National Park Service
U.S. Department of the Interior

Natural Resource Program Center

National Capital Parks–East
Geologic Resource Evaluation Report

Natural Resource Report NPS/NRPC/GRD/NRR—2008/039

THIS PAGE:
Mountian Laurel, Greenbelt Park, Maryland.

ON THE COVER:
Oxon Hill Farm, Part of Oxon Cove Park, Maryland.

NPS Photos by John Grubka and Bill Clark.

National Capital Parks–East

Geologic Resource Evaluation Report

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Geologic Resources Division
Natural Resource Program Center
P.O. Box 25287
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Executive Summary

This report accompanies the digital geologic map for National Capital Parks–East, which the Geologic Resources Division produced in collaboration with its partners. It contains information relevant to resource management and scientific research.

National Capital Parks–East provides a natural haven for the urbanized Washington, D.C., area. This collection of parks lies within the Atlantic Coastal Plain physiographic province and contains a wedge- shaped sequence of mixed sedimentary rocks and deposits of Cretaceous to recent age. They include sandstones, clay beds, gravel deposits, and silts. They form part of a thick mantle of relatively young rock debris, alluvium, regolith, slope deposits, and soils that covers the underlying metamorphic bedrock. This wedge of sediments can be as much as 3,000 m (10,000 ft) thick near the Maryland coast. These deposits (specifically the Arundel Clay of the Potomac Formation) contain fossilized remains of the Maryland State Dinosaur, the sauropod *Astrodon johnstoni*, as well as other Cretaceous- age plants, mollusks, and shark teeth.

The experience of National Capital Parks–East begins with the geology and with the processes from which today's environments, history, and scenery arose. Knowledge of the geologic resources can beneficially influence resource management decisions related to the park. Geologic processes gave rise to rock formations, hills, and valleys. The results of these processes played a prominent role in the history of the Potomac River valley and Washington, D.C. and influenced human use patterns as they developed the modern landscape. Land management issues include air and water quality, urbanization, flood risk, wildlife populations and invasive species, future scientific research projects, interpretive needs, and economic resources. Because many of the 98 sites that compose National Capital Parks–East are monuments or areas too small to contain significant geologic resources, regional descriptions are presented here with issues and recommendations for certain specific units.

National Capital Parks–East protects a vast array of geological resources that warrant consideration in land use planning and in managing visitor use in the parks. Production of a detailed geologic map, wayside exhibits, and a road or trail log, along with a guidebook that ties National Capital Parks–East to the other parks in the Central Appalachian region, would help meet visitor information needs. These items would enhance visitor appreciation of the geologic history and dynamic processes that created the natural landscape of the parks.

Humans have significantly modified the landscape surrounding the parks as well as the geologic system of the area. Urban developments threaten the health of the ecosystem. The dynamic system is capable of noticeable change within a human life span.

The following features, issues, and processes have geological importance and a high level of management significance within the parks:

- Recreation Demands

  National Capital Parks–East provides a substantial, heavily visited protected area between urbanized Washington, D.C., and Baltimore, Maryland. The cumulative effect of visitation places increasing demands on protected areas within the parks. Visitor use includes hiking, camping, picnicking, biking, and horseback riding. The landscape response to potential visitor overuse is a resource management concern and includes visitor safety, especially along stream edges, roads, and near waste facilities.

- Erosion, Sediment Load and Channel Storage

  Erosion from surrounding areas and developments within National Capital Parks–East increases the sediment carried into the park by rivers and streams. Sediment loads and distribution affect aquatic and riparian ecosystems. Sediment loading can change channel morphology and increase the frequency of overbank flooding. Fine- grained sediments transport contaminants in a water system. Sediment loading typically follows a seasonal cycle and may deserve further investigation.

- Water Issues

  Many small streams crossing the landscape within units of National Capital Parks–East, combined with their associated hydrogeologic system as part of the Anacostia River watershed, are a primary resource at these units. The overall quality of the streams is threatened by the constantly increasing urban development in the Maryland–Washington, D.C., metro area. Threats include contamination by waste products and road salts, deforestation along the river edges that increases erosion and sediment load, and acidification from acid rain and snow. A working model of the hydrogeologic system within and between the parks is needed to predict environmental responses to contaminants and to help remediate affected areas.

Included with the geologic issues are a description of some of the cooperative geologic research efforts currently underway and a list of suggested action items related to management issues in National Capital Parks–East.

Introduction

The following section briefly describes the National Park Service Geologic Resource Evaluation Program and the regional geologic setting of National Capital Parks–East.

Purpose of the Geologic Resource Evaluation Program

The Geologic Resource Evaluation (GRE) Program is one of 12 inventories funded under the NPS Natural Resource Challenge designed to enhance baseline information available to park managers. The program carries out the geologic component of the inventory effort from the development of digital geologic maps to providing park staff with a geologic report tailored to a park's specific geologic resource issues. The Geologic Resources Division of the Natural Resource Program Center administers this program. The GRE team relies heavily on partnerships with the U.S. Geological Survey, Colorado State University, state surveys, and others in developing GRE products.

The goal of the GRE Program is to increase understanding of the geologic processes at work in parks and provide sound geologic information for use in park decision making. Sound park stewardship relies on understanding natural resources and their role in the ecosystem. Geology is the foundation of park ecosystems. The compilation and use of natural resource information by park managers is called for in section 204 of the National Parks Omnibus Management Act of 1998 and in NPS- 75, Natural Resources Inventory and Monitoring Guideline.

To realize this goal, the GRE team is systematically working towards providing each of the identified 270 natural area parks with a geologic scoping meeting, a digital geologic map, and a geologic report. These products support the stewardship of park resources and are designed for non- geoscientists. During scoping meetings the GRE team brings together park staff and geologic experts to review available geologic maps and discuss specific geologic issues, features, and processes.

The GRE mapping team converts the geologic maps identified for park use at the scoping meeting into digital geologic data in accordance with their innovative Geographic Information Systems (GIS) Data Model. These digital data sets bring an exciting interactive dimension to traditional paper maps by providing geologic data for use in park GIS and facilitating the incorporation of geologic considerations into a wide range of resource management applications. The newest maps come complete with interactive help files. As a companion to the digital geologic maps, the GRE team prepares a park- specific geologic report that aids in use of the maps and provides park managers with an overview of park geology and geologic resource management issues.

For additional information regarding the content of this report and up to date GRE contact information please refer to the Geologic Resource Evaluation Web site (http://www2.nature.nps.gov/geology/inventory/).

Geologic Setting

National Capital Parks–East is a collection of parks and sites that encompass over 8,000 acres of protected land in the Washington, D.C., area. The group includes Greenbelt Park, Anacostia Park, Kenilworth Park and Aquatic Gardens, Kenilworth Marsh, Mary McLeod Bethune Council House National Historic Site, Frederick Douglass National Historic Site, Capitol Hill Parks, Fort Circle Parks also known as the Civil War Defenses of Washington (including several Civil War forts, Fort Foote, Fort Stanton, Fort Dupont, etc.), Fort Washington Park, Shepherd Parkway, Oxon Cove Park and Oxon Hill Farm, Oxon Run Parkway, Sewall- Belmont House National Historic Site, Baltimore- Washington Parkway, Suitland Parkway, Piscataway Park (with Hard Bargain and National Colonial Farms), Harmony Hall, and others located over 98 sites.

These NPS units protect natural areas for recreation, parkway corridors, archaeological sites, wetlands, river valleys, forests, wildlife, vegetation, historical artifacts and structures, springs and seeps. These parks and sites hosted 1,311,087 recreation visits in 2007, not including the millions of commuters that use the parkways each day. National Capital Parks–East units extend from Anne Arundel County, Maryland at the northern terminus of the Baltimore- Washington Parkway, through portions of the District of Columbia and Prince George's County, Maryland, then southeast to its southernmost point at Piscataway Park in Charles County, Maryland.

The land covered by National Capital Parks–East shelters a haven of natural beauty in the heavily urbanized Washington, D.C., area, all within the Atlantic Coastal Plain physiographic province (fig. 1). This area includes small portions of approximately 20 streams, several of which emerge from underground pipes into the watershed as part of storm water management facilities. Principal waterways include Henson, Fort Dupont, Deep, and Still creeks, Pope and Watts branches, and Oxon Run. Most of the streams are part of the Anacostia River watershed, which in turn is part of the greater Potomac River system. At 616 km (383 miles) in length, the Potomac River is the second largest contributor to the Chesapeake Bay. The Potomac watershed covers 38,018 square km (14,679 square miles) across Maryland, Pennsylvania, Virginia, the District of Columbia, and West Virginia.

The following larger parks with in National Capital Parks–East are described in more detail as they contain significant geologic resources identified during the GRE scoping meeting in 2001.

- Fort Washington (fig. 2) once guarded the water approach to the nation's capital. The existing fort was completed on October 2, 1824. It sits on high ground above the Potomac River on the Maryland shore providing views of Washington, D.C., and Virginia. The park is located 17 km (11 miles) south of Washington, D.C., in Prince George's County. The park protects 341 acres of historical and natural significance on a point of land between the confluences of Swan Creek and Piscataway Creek with the Potomac River.
- Piscataway Park, located in Prince George's and Charles counties, Maryland, was created as part of a project to protect the river view of Mount Vernon and to preserve its appearance from George Washington's time. This 4,625- acre park stretches 10 km (6 miles) from Piscataway Creek to historic Marshall Hall (circa 1725 plantation of Thomas Marshall) on the Potomac River.
- Greenbelt Park (fig. 3) covers more than 1,176 acres in Maryland as a haven of natural beauty in Prince George's County. It was acquired and designated a national park in August 1950 under Public Law 643. In June 2000, one of the park's trails was designated a millennium trail, and in June 2001, another was designated an American discovery trail. The park is located entirely within the Atlantic Coastal Plain physiographic province and in the western shore uplands region. Approximately 1.8 km (1.1 miles) wide and up to 2.1 km (1.3 mile) long, it extends southward from Capitol Drive to Good Luck Road and straddles Deep and Still creeks. These streams flow into the Northeast Branch of the Anacostia River below Indian Creek. The Baltimore- Washington Parkway (described below) bisects the park. Landforms within the park are rolling to steep hills with ravines associated with the two creeks. Elevation ranges from 8 to 60 m (25 to 200 ft) above sea level (National Park Service 2003).
- Baltimore- Washington Parkway bisects Greenbelt Park and provides a 47- km (29- mile) scenic corridor between the urban areas surrounding Washington, D.C., and Baltimore, Maryland. Thousands of commuters use this parkway each day. The parkway opened in 1954 after approval in 1902, but was conceived by Pierre L'Enfant in his 18th century plan to create Washington, D.C., as a city of beautiful parks. The National Park Service manages the portion between Washington, D.C, and Fort Meade, Maryland.
- Oxon Run Parkway is located between Mississippi and Southern Avenues, and 13th Street SE within Washington, D.C. The 126 acres of protected area include wetlands, floodplains, springs, and forests in a natural sanctuary within the urban area.
- Fort Circle Parks or Civil War Defenses of Washington including Fort Dupont, Fort Foote, Fort Stanton, Fort Mahan, Fort Carroll, Fort Davis, and Fort Chaplin were all part of the Union Civil War defenses of Washington, D.C. Fort Dupont covers 376 acres of rolling woodland in Washington, D.C., east of the Anacostia River. The forts themselves are almost all earthworks.
- Oxon Cove Park and Oxon Hill Farm (fig. 4) preserve an early 20th century landscape in eastern Maryland. The park and farm straddle the boundary between Washington, D.C., and Prince George's County, Maryland. The landscape at Oxon Cove Park and Oxon Hill Farm ranges from high river terraces to flat river shorelines to intermediate rolling hills created by the remediation of a landfill in the 1970s.
- Anacostia Park protects more than 1,200 acres in Washington, D.C. It is one of the region's largest and most visited recreation areas. As an urban park, Anacostia includes a sports area, a golf course, a boat launch, and performance facilities. Natural resources within the park include riparian forests and wetlands, river shoreline, and floodplain areas.
- Kenilworth Park and Aquatic Gardens and Kenilworth Marsh (fig. 5) cover some 700 acres within Anacostia Park. These parks owe their origins to both the 1791 L'Enfant Plan for the District of Columbia and the McMillan Plan of 1901 that recommended protecting public parklands along the Anacostia River. In 1938, Kenilworth Aquatic Gardens became the only National Park Service unit devoted to the propagation and demonstration of aquatic plants. This park is a living laboratory for investigating coalification processes (O'Connor 1980). The Kenilworth Marsh covers 77 acres and surrounds the aquatic gardens on three sides. This tidal marsh is all that remains of the once vast tidal wetland areas within the capital. Much of Kenilworth is underlain by a land fill which emits methane used for heating the greenhouse.
- Suitland Parkway, now a scenic highway used by numerous commuters and visitors, was built during World War II to connect Andrews Air Force Base, Bolling Air Force Base, the Pentagon, and downtown Washington, D.C. The parkway opened on December 9, 1944. Suitland Parkway Legislation was enacted in 1949 (63 stat 612). It extends 15 km (9.35 miles) from Washington to Maryland Route 4 in Prince George's County. The National Park Service manages the 10 km (6 miles) of parkway and 610 acres in Maryland. The landscape is forested with ample water provided by numerous streams, and includes wetlands associated with Henson Creek. Among the cultural features in the park are stone road works and nine stone- faced bridges.
- Shepherd Parkway is named for the popular post–Civil War mayor of Washington, D.C., responsible for many of the city's modern upgrades. The Parkway was originally part of the ill- fated Fort Circle Drive proposal, which would have connected the preserved Civil War defenses of Washington, D.C., in a scenic parkway setting. However, delayed by world wars and other national issues, the logistics of the drive proved too difficult to complete. Today, Shepherd Parkway runs parallel to the eastern side of Interstate Highway

295 from Lebaum Street SE to Irvington Street SW in the Congress Heights area of the city. This stretch provides a natural haven for bald eagles nesting in the vicinity.

- Harmony Hall in Prince George's County, Maryland, was acquired by the National Park Service in 1966 under the provisions of the Capper- Crampton Act of 1930. This 18th century Georgian country house was listed on the National Register of Historic Places in 1980 and appears much as it did in 1766 (estimated construction date).
- Frederick Douglass National Historic Site (formerly known as Frederick Douglass Home) was designated on February 12, 1988. This site commemorates the home of the leading 19th century African American spokesman who lived there between 1877 and 1895. The home (named Cedar Hill) and surrounding landscape cover 9 acres within Washington, D.C.

A general description follows of several of the different physiographic provinces of the eastern United States, relevant to understanding the geologic history of the National Capital Parks–East region (fig. 1).

Atlantic Coastal Plain Province

The Atlantic Coastal Plain province is primarily flat terrain with elevations ranging from sea level to about 100 m (300 ft) in Maryland. It extends from New York to Mexico. Sediments eroding from the Appalachian highland areas to the west formed the province. Intermittent deposition during periods of higher sea level over the past 100 million years resulted in a wedge-shaped sequence of soft sediments more than 2,400 m (7,900 ft) thick at the Atlantic Coast. The deposits were reworked by fluctuating sea levels and the continual erosive action of waves along the coastline.

The province continues as the submerged Continental Shelf for another 121 km (75 miles) to the east. The Coastal Plain province stretches from the Fall Line east to the Chesapeake Bay and Atlantic Ocean. Large streams and rivers in the Coastal Plain province, including the James, York, Rappahannock, and Potomac rivers, continue to transport sediment and to extend the Coastal Plain eastward.

Piedmont Province

The "Fall Line" or "Fall Zone" marks a transitional zone where the softer, less consolidated sedimentary rock of the Atlantic Coastal Plain to the east intersects the harder, more resilient metamorphic rock to the west, forming an area of ridges, waterfalls, and rapids (Withington and Coulter 1964). This zone covers over 27 km (17 miles) of the Potomac River from Little Falls Dam, near Washington, D.C., west to Seneca, Maryland. Examples of this transition are present in the Potomac Gorge of the Chesapeake and Ohio Canal National Historic Park and at Great Falls Park. The Piedmont physiographic province encompasses the Fall Line westward to the Blue Ridge Mountains.

The eastward- sloping Piedmont formed through a combination of folding, faulting, metamorphism, uplift, and erosion. The result is a landscape of gently rolling hills in the east starting at 60 m (200 ft) in elevation. The hills become gradually steeper toward the western edge of the province where they reach 300 m (1,000 ft) above sea level. The Piedmont is composed of hard, crystalline, igneous, and metamorphic rocks including schists, phyllites, slates, gneisses, and gabbros.

A series of Triassic age extensional basins occur within the Piedmont. These basins were formed by normal faults during crustal extension. The faults opened basins (grabens) that were rapidly filled with roughly horizontal layers of sediment. Examples include the Frederick valley in Maryland and the Culpeper valley of northern Virginia.

Blue Ridge Province

The Blue Ridge province extends from Pennsylvania to Georgia along the eastern edge of the Appalachian Mountains. Its highest elevations occur in North Carolina near Great Smoky Mountains National Park. Precambrian and Paleozoic igneous, sedimentary, and metamorphic rocks were uplifted during several orogenic events to form the steep, rugged terrain.

Resistant Cambrian age quartzites form Blue Ridge, Bull Run Mountain, South Mountain, and Hogback Ridge in Virginia (Nickelsen 1956). South Mountain and Catoctin Mountain, both anticlines, are two examples of the pervasive folding in the Blue Ridge province. Eroding streams have narrowed the northern section of the Blue Ridge Mountains into a thin band of steep ridges, climbing to heights of more than 1,200 m (4,051 ft at Hawksbill in Shenandoah National Park). The Blue Ridge province is typified by steep terrain covered by thin, shallow soils that result in rapid runoff and low groundwater recharge rates.

Valley and Ridge Province

Long, parallel ridges separated by valleys characterize the landscape of the Valley and Ridge physiographic province. The valleys formed where more easily eroded shale and carbonate formations occur between resistant sandstone ridges. The province contains strongly folded and faulted sedimentary rocks in western Maryland.

Areas dominated by carbonate formations exhibit karst topography. Karst describes landscapes of irregular topography with features such as sinkholes, underground streams, caves, and springs formed by water percolating through water- soluble rock. The karstic eastern portion of the Valley and Ridge province is part of the Great Valley (Shenandoah Valley). The Valley and Ridge province connects to the Piedmont province by streams that cut through the Blue Ridge Mountains.

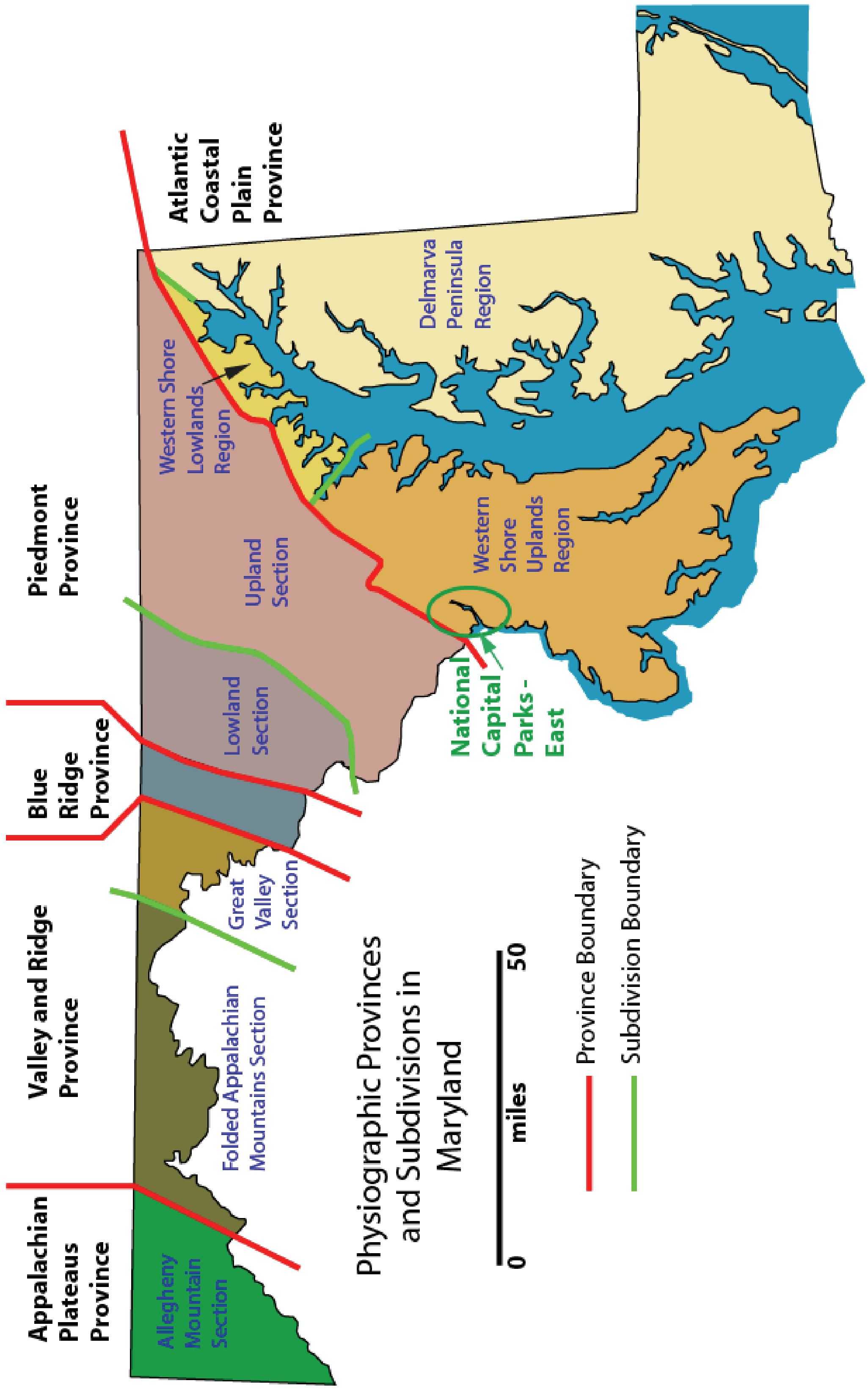

Figure 1: Physiographic provinces and regions of Maryland showing the rough location of National Capital Parks–East. Graphic is adapted from Maryland Geological Survey (2001).

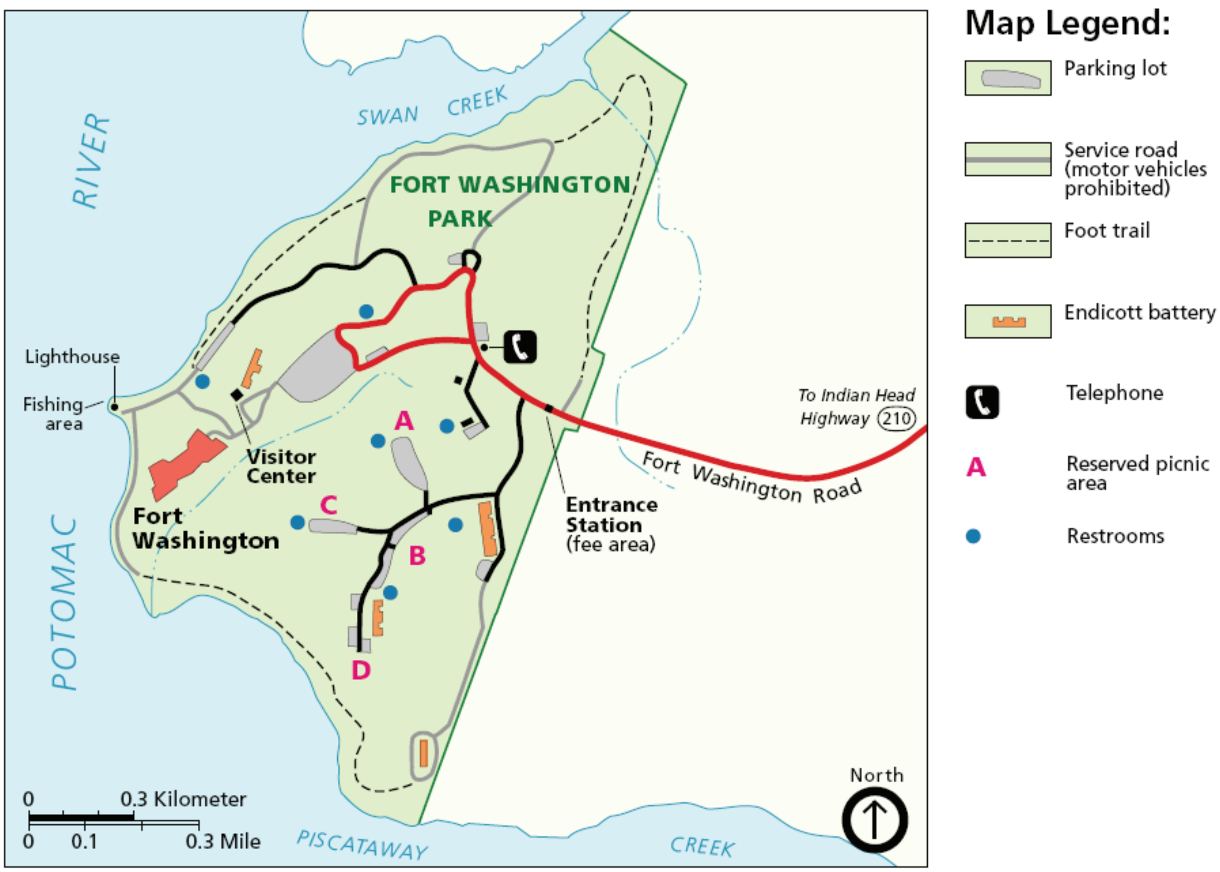

Figure 2: Map of Fort Washington Park's visitor use facilities. Graphic is courtesy of the National Park Service.

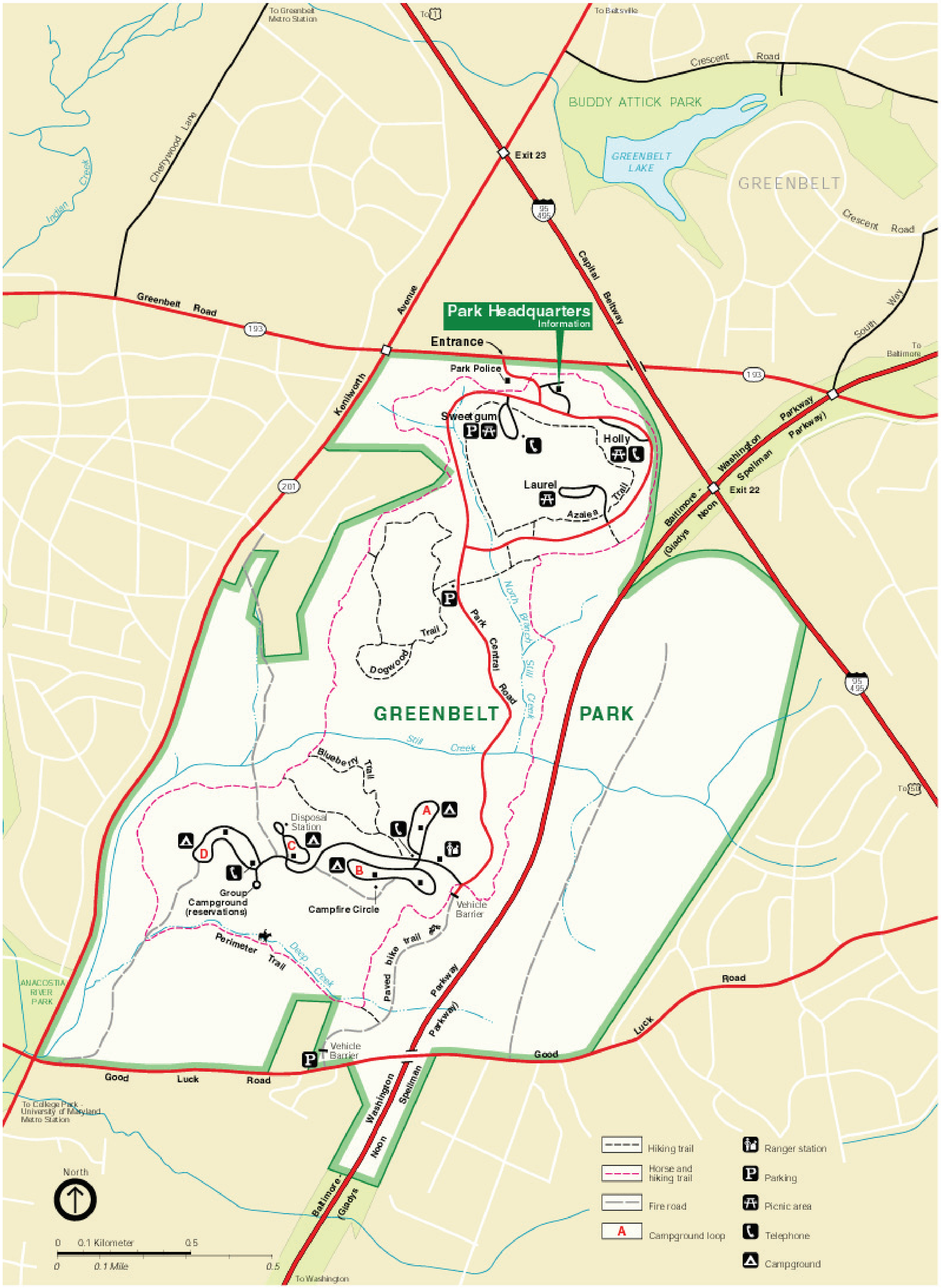

Figure 3: Map of Greenbelt Park's visitor use facilities. Graphic is courtesy of the National Park Service.

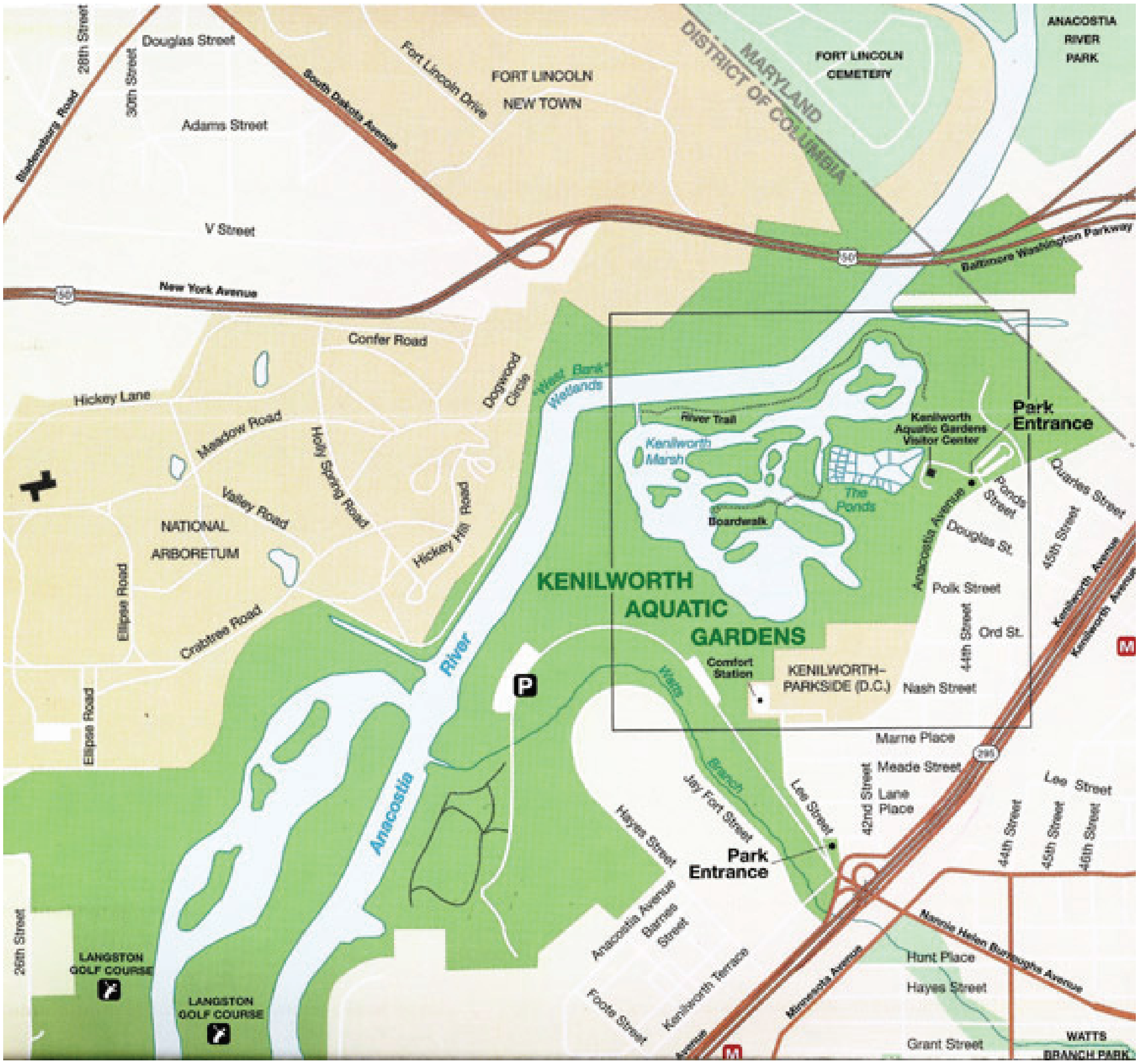

Figure 4: Map of Kenilworth Aquatic Gardens and Marsh as part of Anacostia Park. Map shows visitor use facilities. Graphic is courtesy of the National Park Service.

Figure 5: Photograph of Oxon Cove Park and Oxon Hill Farm showing surrounding rural landscape and rolling topography. Photograph is courtesy of the National Park Service.

Geologic Issues

A Geologic Resource Evaluation scoping session was held for National Capital Parks–East on April 30–May 2, 2001, to discuss geologic resources, address the status of geologic mapping, and assess resource management issues and needs. In addition two other meetings–one held on July 9–11, 2002 focused on monitoring and the other held on May 20, 2002 focused on the influence of geologic processes and humans– are referenced in the following section. This section synthesizes results of these meetings, with emphasis on those issues that may require attention from resource managers.

Recreational Demands

The National Park Service has a mission to protect park resources for the enjoyment of current and future generations. National Capital Parks–East provides numerous recreational possibilities including hiking on 14 km (9 miles) of trails, ball fields, golfing (in Anacostia Park), swimming, musical performances and ice skating (at Fort Dupont's outdoor summer stage and indoor ice rink), boat ramp access, fishing, farm activities, backpacking, bird watching, camping, horseback riding, jogging, nature walks, interpretive programs, bicycling, picnicking, cross- country skiing, and photography. The parks promote activities that do not damage resources or endanger visitors.

More than 1,300,000 people made recreational visits to National Capital Parks–East units in 2007. This number does not include many commuters and other drivers passing through the parks on the Baltimore- Washington, Shepherd, Suitland, and Oxon Run parkways. The large number of visitors places increasing demands on the resources of the parks. Management concerns include trail erosion, water quality, meadowland health, and riverbank erosion.

Many trails wind through preserved biologic, historic, and geologic environments at the parks. Many of these environments are fragile, and off- trail hiking promotes their degradation. The unconsolidated soils and sediments along the more than 20 rivers and streams (e.g. Deep and Still creeks in Greenbelt Park, Oxon Run in Oxon Cove Park, Pope and Watts branches in Kenilworth Park, Henson Creek at Suitland Parkway and Harmony Hall, Fort Dupont Creek at Fort Dupont Park, Anacostia River in Anacostia Park) in National Capital Parks–East are often exposed on slopes with sparse vegetation. This exposure and/or flooding render them highly susceptible to erosion and degradation.

The parks use designated trails and picnic areas to concentrate the impacts of recreation (figs. 2- 4). Trails include the Blueberry, Azalea, Perimeter, and Dogwood trails in Greenbelt Park, and River Trail in Kenilworth Aquatic Gardens and Marsh. Picnic areas such as Holly, Sweetgum, and Laurel in Greenbelt Park as well as campgrounds and their associated facilities all have an impact on the natural resources at National Capital Parks–East. Prohibited use in non- designated areas increases the area of human impact and places delicate ecosystems at risk for contamination and physical damage.

Inventory, Monitoring, and Research Suggestions for Recreational Demands

- Design wayside exhibits to encourage responsible use of park resources.
- Monitor erosion rates along trails; repair and stabilize damage.
- Promote programs to develop a new trail linking Fort Circle parks, taking into account local geologic features and avoiding areas prone to erosion and slope creep.
- Plant stabilizing native vegetation along slopes at risk for slumping and erosion. Special attention is needed for historic earthworks and other structures.

Erosion, Sediment Load, and Channel Storage

Erosion of the landscape within the Anacostia watershed leads to increases in sediment carried by park streams as well as slope instability and gullying of unconsolidated Mesozoic and Cenozoic Atlantic Coastal Plain sediments (including silts and clays) (O'Connor and Withington 1977). The likelihood of slumps and slides increases with undercutting of slopes by roads, trails, and other development in addition to natural erosion.

Slope stability and soil loss is a problem along the Baltimore- Washington and Shepherd parkways as well as in Fort Dupont Park. Unstable slopes are also a management concern in the Newcomb Street area, and a large retaining wall was erected to combat slope creep along O Street SE affecting Shepherd Parkway and Anacostia Park, respectively.

Soils provide an important link between geology and biology, they support life and are derived from underlying bedrock, augmented by transported sediments and nutrients as well as organic matter. The geology, or the rock types, from which the soils are derived, influences soil chemistry. Regional soils developed from a variety of basement rocks including limestone, greenstone, red shale, and quartzite.

The Soil Resources Inventory (SRI) Program of the NPS Geologic Resources Division is working with the Natural

Resources Conservation Service (NRCS) to complete a soil survey for Greenbelt Park, Maryland. This project is underway and projected for completion in 2009. Other units of National Capital Parks–East do not have a SRI scheduled at this time due to lack of funding. Soil resource inventories equip parks with maps showing the locations and extent of soils; data about the physical, chemical, and biological properties of those soils; as well as information regarding potential uses and limitations of each kind of soil type.

The amount of construction caused erosion and pulses of sediment released to waterways depends on the types of mitigation measures required and enforced by local government entities. Slump events of any type cause soil loss and provide a large pulse of sediment to park waterways. Sediment loads and distribution affect aquatic and riparian ecosystems, and sediment loading can result in changes to channel morphology and increase the frequency of overbank flooding. Uncontrolled runoff has great impact on channel morphology. Many local streams are in the process of downcutting and widening, threatening habitat and property. Naturally stable channel morphology is the result of a dynamic equilibrium between mutually adjusting variables such as sediment load, flow magnitude, frequency and duration of high stands (Symborski et al. 1996).

Suspended sediment load is a resource management concern because it can contaminate drinking water sources and increase concentrations of toxic chemicals formerly trapped in river bottom sediments. However, fine- grained sediments are also vital in the overall fluvial transport of contaminants in a water system. Some pesticides can bond to soil particles that are then transported by erosion (Anderson et al. 2002). The National Park Service manages portions of the bottom of the Anacostia River and cooperates with the Environmental Protection Agency (EPA) on toxic substance issues through the Anacostia Watershed Toxics Alliance (reference http://www.chesapeakebay.net/awta/guide/home/awta.html). Other agencies such as the Washington Area Council of Governments and the Anacostia Watershed Coordination Committee are also cooperating with the National Park Service for work on the Anacostia River.

The National Park Service Water Resources Division is monitoring sites along the river and has drilled several cores near the Washington Navy Yard. Information from these cores, in addition to local piezometer (pore pressure gauge) data, adds greatly to the understanding of sediment composition, changes, and distribution in the watershed. The Water Resources Division should be contacted with further concerns.

Channel storage of fine sediment and the contaminants contained therein follow a seasonal cycle. This cycle is subject to hydrologic variability with increased availability during the high stands of spring and decreased availability during the low stands of autumn. Fine- grained sediments do not travel downstream in a single pulse but are often resuspended bottom material (Miller et al. 1984). This intermittent transport of contaminants and fine- grained sediment increases the affected area.

Inventory, Monitoring, and Research Suggestions for Erosion, Sediment Load, and Channel Storage

- Monitor erosion rates by establishing key sites for repeat profile measurements to document rates of erosion or deposition and reoccupy, if possible, shortly after major storms. Repeat photography may be useful.
- Perform a comprehensive study of active erosion and weathering processes at the park, accounting for slope aspects, location, and likelihood of instability.
- Assess impacts of human activity on sedimentation and erosion including facility placement, recreation, storm management systems, parking lots, etc.
- Monitor sediment inflow originating from unstable fill to the Yeager Tract to determine if stability is realized at Greenbelt Park.

Water Issues

Annual precipitation in Washington, D.C., averages ~111 cm (43.7 inches) per year with almost half of the rain coming in the summer months during storms of short duration. Water resources are under constant threat of contamination and overuse because of development of in surrounding areas. Sedimentation increases when land-clearing and earth- moving for development exposes barren soil to erosion. Water temperature increases because of the insulating nature of impervious surfaces (Allen and Flack 2001). Runoff from a parking lot on a hot July day is at a much higher temperature than the water temperature of runoff from a grassy slope.

Much of more than 20 waterway corridors within National Capital Parks–East are beyond National Park Service jurisdiction. Deep and Still creeks, Henson Creek, Oxon Run, Fort Dupont Creek, Pope and Watts branches, and the Anacostia River are some of the more prominent waterways managed in part by Greenbelt Park, Suitland Parkway and Harmony Hall, Oxon Run Park, Fort Dupont Park, Kenilworth Park, and Anacostia Park, respectively. The National Park Service has little control over water quality, flow, and sediment load. Groundwater in most of National Capital Parks–East trickles through unconsolidated Cretaceous and younger aged sediments. Groundwater discharges directly into the park's streams and local springs from pipes and from those places where the water table intersects the surface.

The strongest regional effects on water quality in the creeks and rivers are due to increased urban development and increased surface runoff, which results from the addition of impervious surfaces in the basin, such as roads, parking lots, and playgrounds among others (Anderson et al. 2002). Unless there is mitigation of run- off by storm water management systems, impacts from impervious surfaces, begin when they cover 10% of the watershed. A 20% land cover of the watershed by impervious surfaces leads to severe impacts on the watershed (Allen and Flack 2001).

Urban developments lead to reduced base flow as a result of the reduction of the infiltration of groundwater and the channeling of water through storm water management facilities, thus contributing to higher peak flows. Higher peak flows can result in destructive flooding conditions along waterways. These high flows destroy viable habitat. Further impacts to watershed health include chemical pollutants (oil, grease, brake fluid, coolant, etc.) leaking from vehicles along roadways, in parking lots, and in construction areas; litter and trash washed in from other areas,; and flushes of sediment from new construction sites.

Increased human habitation in surrounding areas also leads to long term increases in pesticides, fertilizers, and herbicides as well as increases in mercury, arsenic, lead, aluminum, sewage, pharmaceuticals, and endocrine disrupters within the hydrologic regime. Road crossings and water management culverts also serve to fragment viable habitat for plant and animal species in the area.

The removal of culverts from streams has been proposed in Anacostia and other parks, with potential for cooperation with the U.S. Army Corps of Engineers (COE). Culvert removal may promote the regrowth of fringe wetlands, but may impact flood- control levees. Several of these flood- control levees are routinely inspected by the COE. Many are on NPS land along the Anacostia River. The degree of NPS responsibility to maintain these structures is not well defined.

The integrity of the watershed is directly reflected in the quality of water in the creeks and rivers. Streams integrate surface runoff and groundwater flow and thus provide a cumulative measure of water quality within the hydrologic regime.

Differences in water quality stem from a variety of natural and non- natural sources. For instance, major geochemical differences exist among water samples from areas underlain by different lithologic units (Bowser and Jones 2002). It is important to know the mineral compositions for both the aqueous phase and the host rock.

The movement of nutrients and contaminants through the hydrogeologic system can be modeled by monitoring the composition of system inputs, such as rainfall, and outputs, such as streamflow. Other input sources include wind, surface runoff, groundwater transport, sewage outfalls, landfills, and fill dirt. Consistent measurement of these parameters is crucial to establishing baselines for comparison.

Inventory, Monitoring, and Research Suggestions for Water Issues

- Work with the NPS Natural Resource Program Center's Water Resources Division to address specific areas of concern and design effective water quality monitoring programs.
- Establish and/or maintain working relationships with the U.S. Geological Survey, the Environmental Protection Agency, and the Maryland Geological Survey as well as local to national conservation groups to study and monitor park watersheds and the hydrology of the area for applications in hydrogeology, slope creep, stream bank erosion, and other geologic hazards.
- Monitor morphologic changes in stream channels within the parks.

General Geology

A meeting held in August 2002 to assess geologic monitoring objectives for the National Capital Region Vital Signs Network (including Wolf Trap National Park for the Performing Arts) identified the following geologic resource components: soils and bedrock, ground water, bare ground and exposed rock, karst, surface water, coastal areas, and riparian areas and wetlands. Resource management could benefit from consideration of these components and their contributions to the entire ecosystem.

Stresses to these components include nutrient and chemical contamination, sediment erosion and deposition, shoreline changes, and geo- hazards. These stressors are potential areas for ecosystem monitoring. Primary sources of stress to the natural resources at National Capital Parks–East that were identified are: acid rain, atmospheric deposition of contaminants, urban development, climate change, abandoned mines and wells, and visitor use.

Digital geologic data facilitates science based decision making for resource managers by allowing integration with other spatial data in a GIS. Potential uses of digital geologic data include:

1. identification and description of critical habitats for rare and endangered species;
2. hazard assessments for events such as floods, rockfalls, or slumps;
3. creation of interpretive programs to illustrate the evolution of the landscape and Earth history of the park in lay- person terms;
4. identifying the location of sources of aggregate and building stone for historical reconstruction;
5. determining environmental impacts for any new construction;
6. inventory of natural features such as springs, cliffs, marker beds, fossil localities, and caves;
7. characterizing land use; and
8. defining ecological zones and implementing conservation plans (Southworth and Denenny 2003).

Inventory, Monitoring, and Research Suggestions for General Geology

- Develop a geological site bulletin or brochure, and collect and display geological data using GIS/GPS.
- Investigate the surficial geologic story at the parks and develop an interpretive program to relate the current landscape, ecosystem, history, and biology to the geology.

Landscape Change

Since the earliest settlements in the Washington, D.C., area the landscape has been altered by cutting forests, removing soils, flattening hills, filling valleys, construction of roads and parkways, and urban development. Development has resulted in significant changes in the elevation and slope of the land surfaces at National Capital Parks–East. Typically, hills are flattened and stream valleys and marshes are filled in. According to a comparison between current digital elevation model (DEM) data and a pre- development DEM from 1889 topographic data, Chirico and Epstein (2000) documented as much as 18 m (60 ft) of elevation change for the Philadelphia area.

Similar data are available for this comparison for Washington, D.C., including U.S. Coast and Geodetic Survey 1:4,800 scale maps from 1878 and 1888, sewer- line maps from 1891 and 1892, and digital U.S. Geological Survey topographic map data from surveys in 1996–1999. Significant topographic change from urban development in the area has occurred affecting the rates of runoff, infiltration, and erosion.

Elevation data are needed throughout National Capital Parks–East to monitor shoreline marshes such as Accokeek marsh, as well as the restored marsh at Kenilworth Park. Very slight changes in elevation on the scale of 0.3 m (1 ft) appear to significantly effect vegetation distribution in wetlands. Implications exist for assessment of regulations and methodologies for marshland restoration and remediation.

Seawalls are common along the Anacostia River, affecting shorelines within Anacostia Park and farther downstream. Seawalls and reductions in woody debris along shores reduce protection from erosion, affecting coastal marshes and other areas farther downstream such as Piscataway Park.

Several of the parks within National Capital Parks–East include reclaimed landfills, all of which were operational before environmental standards were enforced by regulations. The total area within the National Capital Parks–East units occupied by former landfills is close to 300 acres. The old city dump sits beneath portions of Kenilworth Park and may pose a methane hazard (O'Connor 1980). Cooperative efforts with the EPA and U.S. Geological Survey monitor outflow from landfills. These efforts attempt to prevent toxic leachates from reaching the Potomac and Anacostia rivers. In addition to surface water quality, soil and groundwater quality are necessary parameters to define in landfill area impact studies.

Inventory, Monitoring, and Research Suggestions for Landscape Change

- Determine impacts of human landscape change activities on sedimentation and erosion processes. Focus on facility placement, culverts, parking lots, stream and storm sewer outfalls, roads, etc.
- Monitor morphological changes in slopes and stream channels, relating them to any past developments.

Geologic Features and Processes

This section describes the most prominent and distinctive geologic features and processes in National Capital Parks–East.

Cretaceous Age Fossils

Dinosaurs inhabited central Maryland during much of the Mesozoic Era. The regional climate ranged from a shallow, warm sea to tropical lowlands. At least 12 species of dinosaurs have been documented in the area from the Late Triassic (228 Ma) to the Late Cretaceous (70 Ma). Intermittent volcanic activity and heavy sedimentation from the highlands to the west during the Mesozoic provided ideal conditions for fossil formation and preservation (Reger 2005). Sediments and volcanic ash rapidly buried animal and plant remains. Remains not destroyed by scavenging or erosion were preserved as the sediments lithified.

In the National Capital Parks–East area, dinosaur and other fossils are found in the Arundel Clay of the Lower Cretaceous Potomac Formation. To the east of the parks, other units including the Severn and Mt. Laurel Formations from the Upper Cretaceous also contain fossils. The Upper Triassic Gettysburg Shale, located in the Frederick Valley northwest of National Capital Parks–East, is fossiliferous. Jurassic age rocks are not exposed in Maryland (Reger 2005).

In 1858, Philip T. Tyson discovered two dinosaur teeth in an open pit iron mine within the Arundel Clay (fig. 6). This mine was near Muirkirk in Prince George's County on the property of J.D. Latchford. The species of these teeth was named *Atrodon johnstoni* by Dr. Joseph Leidy, making it the first sauropod dinosaur described in North America. Other exploration yielded a wealth of fossils in the area. At one time, the Arundel Clay between Washington and Baltimore was known as "dinosaur alley" (Kranz 2004; Conkwright 2005).

Fossils from this clay now reside in many museums, including the Smithsonian Institution in Washington, D.C. *Astrodon johnstoni*, the official Maryland State Dinosaur as of October 1 1998, was a large herbivorous species growing to lengths of 18 m (60 ft) or more (fig. 7). Recent explorations in the area have revealed partial femurs, fragments of which are more than 1 m (3 ft) in length and weigh approximately 40 kg (90 lbs) (Kranz 2004; Conkwright 2005).

With urban development rapidly covering the land surface near National Capital Parks–East, the parks may be preserving valuable dinosaur, mollusk, plant, and shark fossils for future study. In December 1995, the Maryland–National Capital Park and Planning Commission acquired J.D. Latchford's property for the development of a dinosaur park (Kranz 2004).

A Paleontological Resource Inventory and Monitoring Report has been completed for the National Capital Region, which includes National Capital Parks–East. This literature based inventory has been prepared for NPS administration and resource management staff and is not intended for distribution to the public. NPS staff may contact the Geologic Resources Division to obtain this report.

Geology and History at National Capital Parks–East

The entire Potomac River valley is rich in archaeological resources that document the human habitation of the area for the past 10,000 years. The geology of the area has always attracted people to its vast natural resources. Ancient people came to use the unique stones found there for toolmaking, including chert and metarhyolite, establishing base camps and processing sites in several locations. The river provided Algonquin Native Americans and other competing tribes with a concentration of fish, game, and numerous plant species as well as wood, stone, shell, and bones necessary for tools and trade.

Geology played a vital role in early European settlement success. In the area around Washington, D.C., rivers supported local trade and provided resources such as fertile floodplains for the inhabitants. Forests were cleared for settlements and agriculture. For over 150 years corn, tobacco, and other crops provided a livelihood for thousands of early Americans. However, poor land use practices led to erosion and stripped the soils of nutrients. Many areas were left barren and exposed to intense erosion. Reforestation since the early 1900s has reintroduced stable mixed pine and deciduous forests to the area.

The geology influenced placement of the local river crossings and fords. Early railroads and roads often followed the trends of natural geologic features. Interpretation of the impacts of geologic controls during settlement and development of the area provides an opportunity to educate the public about the interconnectedness between history and geology. This information yields a deeper understanding of the landscape.

One of the major goals of the National Park Service is to preserve the historical context of the area. Several management challenges occur in maintaining this landscape because it often means resisting natural geologic changes. Geologic slope processes such as landslides, slumps, slope creep, and chemical weathering, are constantly changing the landscape at the parks and threatening historic features. Runoff erodes sediments from any open areas and carries them down streams and gullies. Erosion naturally diminishes higher areas and fills in the lower areas, distorting the historical context of the landscape.

The following sections highlight geology- history connections at specific units within National Capital Parks–East.

Fort Circle Parks

The Fort Circle Parks are a group of defenses active during the Civil War (begun in 1861) in defense of the Union Capital of Washington, D.C. (fig. 8). In 1861, the capital was considered an island amidst Confederate Virginia and Maryland whose loyalty to the Union was divided. Today these parks are largely earthworks, managed in part by three separate National Park Service units: Rock Creek Park, George Washington Memorial Parkway, and National Capital Parks–East. The latter unit contains Fort Washington (not among the Fort Circle Parks, see below), Fort Dupont, Fort Foote, Fort Stanton, Fort Mahan, Fort Carroll, Fort Davis, Fort Chaplin, and Fort Greble.

Strategic placement of these forts was designed to take defensive advantage of any geologic features such as ridges, hills, shorelines, river crossings, natural ports, etc. By the end of the war, 68 forts and 93 gun batteries dotted the high ground, forming a defensive ring around the city. Fort Dupont's siege guns defended the Eleventh Street Bridge over the Anacostia River (reference http://www.nps.gov/nace/ftdupont.htm).

Like Fort Dupont, many of the Circle Forts had sides made of earth, protected by a deep moat with felled trees pointing outward (fig. 9). Most of these forts are now low earthworks, on the brink of disappearing due to erosion. Other historic factors considered by the National Park Service include the activities of the Civilian Conservation Corps at various Circle Fort sites during the 1930s, and communities and historic neighborhoods that developed around the fort sites (see http://parkplanning.nps.gov for latest projects).

These historic structures are all vulnerable to change due to the geologic processes of weathering and erosion. Finding a balance between the need to let nature take its course and the need to preserve historic features is a constant struggle because the goal of the parks is to preserve both the natural and historical context of the area. This aim is under constant pressure from both the continuous natural processes of erosion and weathering and the demands of increasing local population and urban development.

Issues also arise from the sometimes opposing values between cultural and natural resource management. For example, a proposal for restoration of a historic fort may consist of removing surrounding natural resources or planting exotics. The streams in the parks are also sometimes changed to protect trails, buildings, and stream banks from being undercut. These efforts attempt to reverse many natural geologic changes.

Piscataway Park

The earliest inhabitants of the Piscataway area were members of the Piscataway (Conoy) Tribe. These Native Americans spoke Algonquian and lived in permanent villages (Marshall 1997). About 30 dwellings were present prior to the first English landing in Maryland in 1634. The tendency of European settlement in the area was to follow the shores of the Potomac River (Marshall 1997). This settlement pattern allowed easy access to the trade routes and vast resources of the riverways, but also left settlements vulnerable to flooding and with increased development, shoreline erosion increased as well.

The Piscataway Tribe was a friendly ally of the European settlers in struggles with the Susquehannock and Seneca tribes. At one point in 1680, the Piscataways were forced to seek shelter from Seneca- Susquehannocks raids in the many surrounding wetlands of Zachia Swamp in southern Charles County (Marshall 1997).

Early plantation owners, including Thomas Marshall of nearby Marshall Hall, contributed to the development of the landscape by clearing forests and fields, reshaping topographic highs and filling in lows.

In addition to archaeological potential, Piscataway Park also has significant paleontological resources that have yet to be formally catalogued as well as local seeps that provide direct access to groundwater.

Fort Washington Park

Fort Washington's masonry walls stand as one of the few U.S. seacoast fortifications still in original form. The fort sits on a relatively flat upland plateau of high ground (highly graded in the 19th century) overlooking the Potomac River, bounded to the northwest, west, and south by moderate to steep slopes that drain to the Potomac. This fort once guarded the water approach to Washington, D.C., against wooden ocean- going warships.

Current plans are being made to stabilize the historic fort (see http://www.nps.gov/archive/fowa/ea/). The fort has been weakened by years of moisture (both meteoric and from natural seeps and springs) and vegetation intrusion into the masonry walls. Stabilization plans involve developing a drainage system, remediating vegetation encroachment, and supporting earthen terraces, slopes, buildings, and other historic features. Prominent outcrops of Marlboro clays create landslide hazards at Fort Washington Park (O'Connor 1980). These loose clays have played a role in undermining the historic structures.

This park is a stratigraphic locality for lower Tertiary marine units and associated fossils. Additionally, Fort Washington Park contains gypsum crystals in the substrate. Because these geologic resources might attract illegal collectors, they raise resource protection concerns.

Anacostia Park

Early settlement in this area organized around a natural deep- water port on the Anacostia River. The Bladensburg settlement was founded in the area in 1742. By 1800 the depth of the channel at Bladensburg was dramatically reduced from 14 m to 8 m (46 to 26 ft) by silting. Sediment eventually filled in much of the tidal estuary and subsequently the deep- water port at Bladensburg.

Erosion induced by agriculture and urbanization silted the river further and caused severe flood hazards. In response to flooding, dikes were built in the 1950s and the Anacostia River Flood- Control Project was started by the Army Corps of Engineers to control flooding and improve navigation along the Anacostia River (O'Connor and Withington 1977).

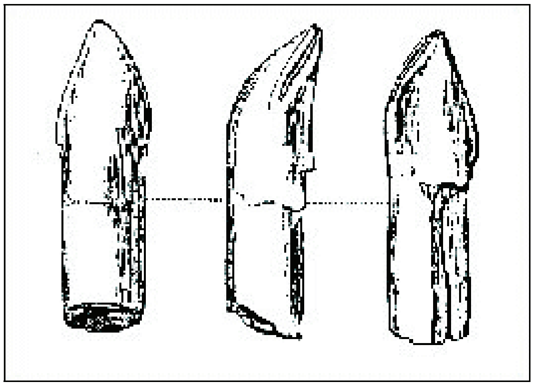

Figure 6: Drawings of *Astrodon johnstoni* tooth after Leidy (1865). Graphic is courtesy of the Maryland Geological Survey: http://www.mgs.md.gov/esic/fs/fs12.html (accessed April 11, 2008).

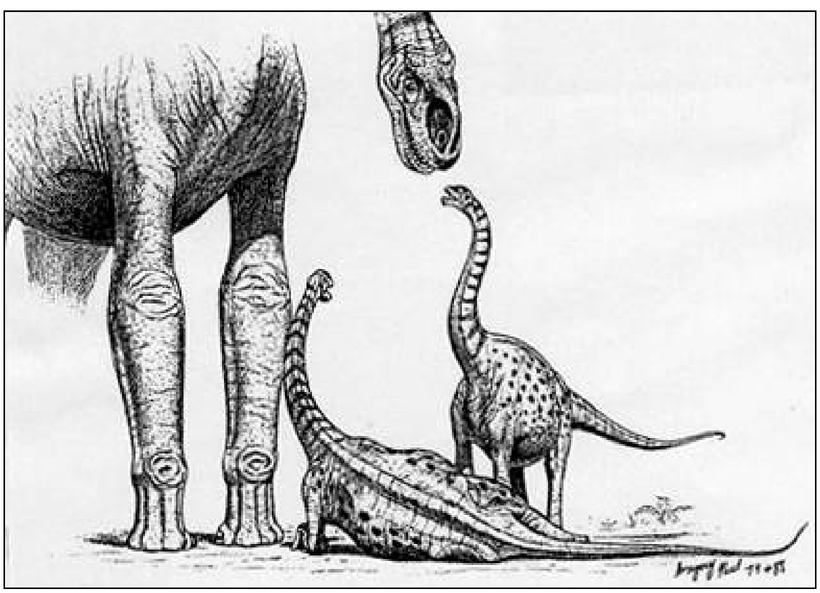

Figure 7: Drawing of the Maryland State Dinosaur, *Astrodon johnstoni* by Gregory Paul, 1979, 1988. Graphic is courtesy of the Maryland Geological Survey: http://www.mgs.md.gov/esic/fs/fs12.html (accessed April 11, 2008).

Figure 8: Drawing showing the location of the series of forts belonging to the Fort Circle Parks of National Capital Parks–East. Drawing is courtesy of the National Park Service: http://www.nps.gov/nace/ftdupont.htm (accessed July 11, 2005).

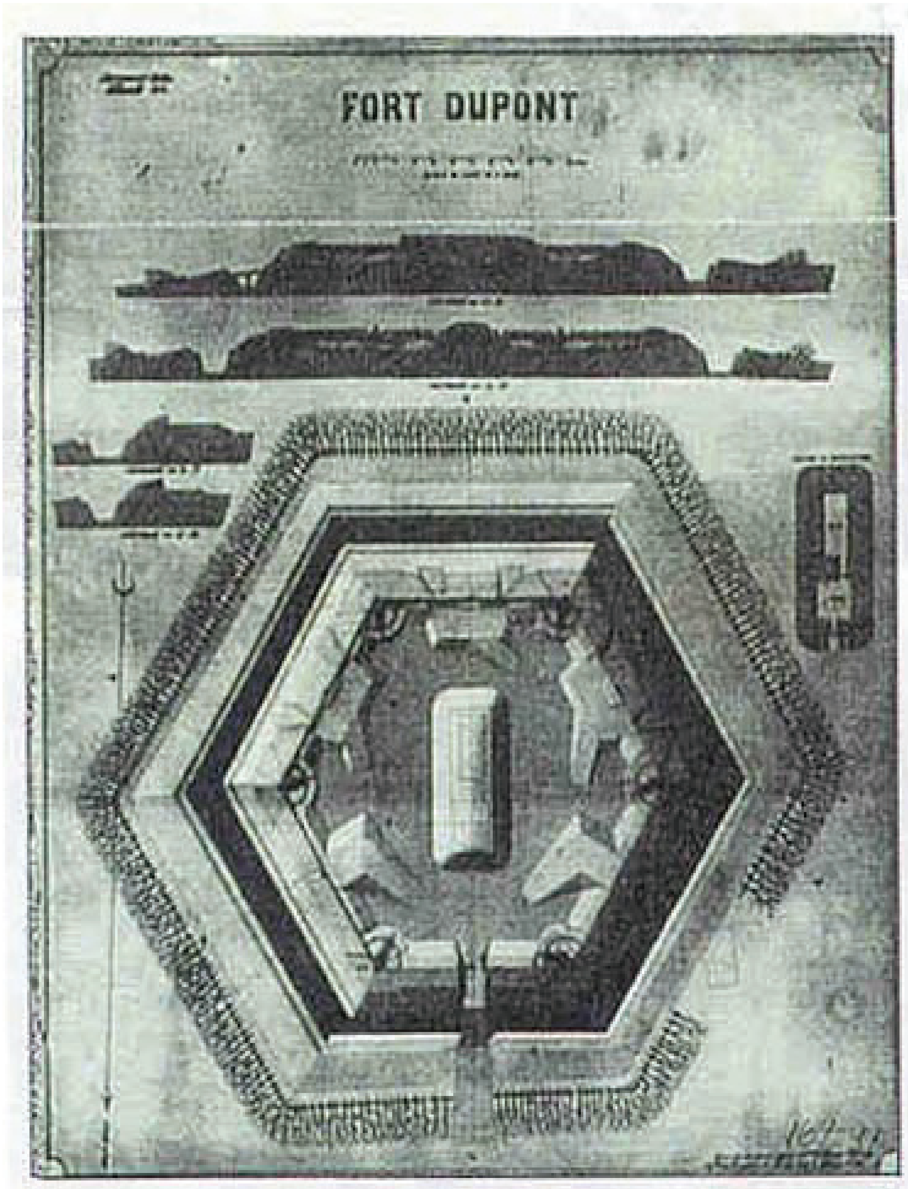

Figure 9: Drawing of Fort Dupont showing six-sided shape and surrounding moat. Image is courtesy of Fort Ward Museum.

Map Unit Properties

This section identifies characteristics of map units that appear on the Geologic Resource Evaluation digital geologic map of National Capital Parks–East. The accompanying table is highly generalized and is provided for background purposes only. Ground-disturbing activities should not be permitted or denied on the basis of information in this table. More detailed map unit descriptions can be found in the help files that accompany the digital geologic map or by contacting the NPS Geologic Resources Division.

The map units that are exposed west of National Capital Parks–East and underlie the entire area at depth include those of the Potomac Terrane of the Piedmont physiographic province. The Potomac terrane is bound on the west by the Pleasant Grove fault and is covered to the east by Atlantic Coastal Plain sediments (Kunk et al. 2004). These ancient sedimentary and volcanic rocks were thrust along faults during deposition in a Neoproterozoic–Early Cambrian oceanic trench setting mixed with unconsolidated sediments to form a mélange, or mixture, of rocks.

This mélange then metamorphosed into deformed crystalline rocks. Late Proterozoic–Early Cambrian amphibolites, metagabbros, and actinolite schists are present in pods throughout the area (Fleming et al. 1994). The units commonly associated with this mélange of rocks west of the parks include the Mather Gorge, Sykesville, and Laurel formations as well as the various igneous intrusive rocks.

This metamorphic bedrock underlies much of northwestern Washington, D.C., and Maryland. Locally, the bedrock is thick- bedded to massive, bearing boulders and pebbles. The overall composition is arenaceous (consisting wholly or in part of sand- size fragments) to pelitic (derived from mixed mudstones) metamorphic rock that in outcrop typically appears as a medium- grained gneiss or schist with garnet- oligoclase (a sodium feldspar)- mica- quartz. The apparent thickness of this unit is 4,600 m (15,000 ft) (Maryland Geological Survey 1968). Debate over formation designations continues today among geologists.

A very thick mantle of rock debris, regolith, soils, and transported alluvium and colluvium covers most of the bedrock in the Greenbelt Park area forming a wedge that thickens to the east. Within National Capital Parks–East, the Cretaceous Potomac Formation dominates the map units (Diecchio and Gottfried 2004). These deposits include interbedded, unconsolidated protoquartzitic to orthoquartzitic (well- sorted subrounded to rounded quartz grains, respectively) argillaceous (clay- rich) sands, gravels, white to dark gray silts, and clays.

Local thickness of the Potomac Formation is 240 m (800 ft) (Maryland Geological Survey 1968). Blue quartz grains from Grenville rocks of the Blue Ridge province to the west, are present in this formation (Diecchio and Gottfried 2004). Fleming et al. (1994) divided the Potomac Formation into a coarse- grained and a fine-grained unit. The Maryland Geological Survey's 1968 map divides the Potomac into the Raritan and Patapsco formations (containing crossbedded sands, silts, and clays), the Arundel Clay (with lignitic or organic- rich clay and siderite or iron- enriched carbonate concretions, including dinosaur fossils), and the Patuxent Formation of coarser sands and gravels.

Atop the Cretaceous sediments in the National Capital Parks–East area are Tertiary deposits from Paleocene thru Pliocene. Marine clays of the Brightseat Formation record a high- stand of sea level, whereas the Aquia Formation and Marlboro Clay record a later sea transgression following a period of erosion. Eocene units include the Nanjemoy, Piney Point, and Chickahominy formations. Oligocene sediments are missing from this part of Maryland. Miocene beds include the Calvert, Choptank, St. Mary's, and Eastover formations (Ward and Powars 2004).

Gravels, sands, silts, and clays of Pleistocene and Holocene age alluvium line the creek valleys in National Capital Parks–East. The sands are commonly orange to brown, locally cemented with limonite, with some interbedded red, white, or gray clay (Maryland Geological Survey 1968). Flood deposits are also present locally. Elsewhere, artificial fill is associated with the anthropogenic development of the area (Maryland Geological Survey 1968; Southworth et al. 2001).

The geologic units in the following table and their geologic features and properties correspond to the units found in the accompanying digital geologic data. Source data for the GRE digital geologic map are from:

Scott Southworth and Danielle Denenny, 2006, Geologic Map of the National Parks in the National Capital Region, Washington D.C., Virginia, Maryland and West Virginia, USGS, OF 2005- 1331, 1:24,000 scale

The following pages present a table view of the stratigraphic column and an itemized list of features per rock unit. This table includes several properties specific to each unit present in the stratigraphic column including age, name and map symbol, unit description, resistance to erosion, suitability for development, hazards, paleontologic resources, cultural resources, mineral occurrence , habitat, recreational use, and geologic significance.

Geologic History

This section describes the rocks and unconsolidated deposits that appear on the digital geologic map of National Capital Parks–East, the environment in which those units were deposited, and the timing of geologic events that created the present landscape.

National Capital Parks–East is located at the western edge of the Atlantic Coastal Plain physiographic province near the Fall Line, which divides the Coastal Plain from the Piedmont to the west. The parks contain features that are associated with the long geologic history of the eastern United States. A regional perspective is presented here to connect the landscape and geology of the parks to their surroundings.

The recorded history of the Appalachian Mountains begins in the Proterozoic (figs. 10 and 11). In the mid-Proterozoic, over 1 billion years ago during the Grenville Orogeny (fig. 12A), a supercontinent (Rodinia) had formed comprising most of the continental crust in existence at that time (Diecchio and Gottfried 2004) including North America and Africa. The sedimentation, deformation, plutonism (the intrusion of igneous rocks), and volcanism are manifested in the granites and gneisses exposed through intense erosion in the core of the modern Blue Ridge Mountains (Harris et al. 1997).

These Grenville age rocks were deposited over a period of 100 million years and are more than a billion years old, making them among the oldest rocks known from this region. Following uplift, the rocks were exposed to erosion for hundreds of millions of years. Their subdued surface forms a platform upon which all other rocks of the Appalachians were deposited (Southworth et al. 2001).

The late Proterozoic, roughly 800–600 million years ago, brought a tensional, rifting tectonic setting to the area perhaps resulting from mantle convection changes (fig. 12B) (Diecchio and Gottfried 2004). The crustal extension created fissures through which massive volumes of basaltic magma extruded. This volcanic activity lasted tens of millions of years and alternated between flood basalt flows and ash falls. The metamorphosed remnants of these igneous rocks form the Catoctin Greenstones of Shenandoah National Park and Catoctin Mountain Park west of National Capital Parks–East.

Because of tensional tectonic forces, the supercontinent broke up into islands formed from crust of the Grenville Orogeny and a sea basin began to open that eventually became the Iapetus Ocean. This basin subsided and collected many of the sediments that would eventually form the Appalachian Mountains. Thick layers of sand, silt, and mud deposited in the Iapetus Ocean underwent regional deformation and extensive metamorphism that became the Sykesville and Mather Gorge formations. Large blocks of eroded fragments from the Grenville highlands mixed with these sediments (Southworth et al. 2000b).

Massive deposits of sands, silts, and muds in near shore, deltaic, barrier island, and tidal flat areas were associated with a passive margin, shallow marine setting along the eastern continental margin of the Iapetus Ocean (fig. 12C). Some of these deposits are preserved today in the Chilhowee Group in Central Maryland (Schwab 1970; Kauffman and Frey 1979; Simpson 1991). Portions of the sediments were deposited as alluvial fans, large submarine landslides, and turbidity flows, which today preserve the dramatic features of their emplacement. These early sediments are exposed on Catoctin Mountain, Short Hill–South Mountain, Blue Ridge–Elk Ridge, and in areas to the west of the parks as the Chilhowee Group (Loudoun Formation, Weverton Formation, Harpers Formation, and Antietam Formation) (Southworth et al. 2001).

As the source of clastic sediment diminished from the eroded Grenville Mountains, huge masses of carbonate sediment were deposited over the Chilhowee Group forming the Cambrian age Tomstown Dolomite and Frederick Limestone as well as the Upper Cambrian to Lower Ordovician Grove Limestone (Means 1995; Diecchio and Gottfried 2004). They formed a grand platform, thickening to the east, that persisted during the Cambrian and Ordovician periods (545–480 Ma) and form the floors of Frederick and Hagerstown valleys (fig. 13A) (Means 1995).

Somewhat later (540, 470, and 360 million years ago) pulses of igneous granodiorite, pegmatite, and lamprophyre, respectively, intruded the sedimentary rocks including those of the Mather Gorge Formation. The entire pile of sediments, intrusives, and basalts were deformed and metamorphosed into schists, gneisses, marbles, slates, and migmatites during several episodes of mountain building and continental collision (described below) (Southworth et al. 2000a).

Taconic Orogeny

From Early Cambrian through Early Ordovician time, orogenic activity along the eastern margin of the continent began again. The Taconic orogeny (~440–420 Ma in the central Appalachians) was a volcanic arc–continent convergence. Oceanic crust, Grenville remnant islands, and the volcanic arc, developed from a subduction zone in the Iapetus basin, were thrust onto the eastern edge of the North American continent as the composite continent Gondwana pushed westward (Diecchio and Gottfried 2004). These additions to the continent now form the Piedmont physiographic province. Gondwana consisted of the existing crust of South America, Africa, Antarctica, India, Australia, portions of southwest Europe and even at one time included Florida (Kazlev 2002).

The Taconic orogeny involved the closing of the ocean, the subduction of oceanic crust, the creation of volcanic arcs, and the uplift of continental crust (fig. 13B) (Means 1995). Initial metamorphism of the igneous and sedimentary rocks of the Sykesville and Mather Gorge formations into schists, gneisses, migmatites, and phyllites occurred during this orogenic event.

The crust bowed downwards in front of the rising Taconic Mountains creating a deep basin that filled with mud and sand, which had eroded from the highlands to the east in response to the overriding plate thrusting westward onto the continental margin of North America (Harris et al. 1997). This so- called Appalachian basin was centered on what is now West Virginia (fig. 13C). These infilling sediments covered the grand carbonate platform and are today represented by the shale of the Ordovician Martinsburg Formation (Southworth et al. 2001).

The oceanic sediments of the shrinking Iapetus Ocean were thrust westward onto other deepwater sediments of the western Piedmont during the Late Ordovician. This deformation occurred along the Pleasant Grove fault and other local faults, such as the Plummers Island fault and the Rock Creek shear zone. Sandstones, shales, siltstones, quartzites, and limestones continued to be deposited in the shallow marine to deltaic environment of the Appalachian basin. These rocks, now metamorphosed, currently underlie the Valley and Ridge province to the west of National Capital Parks–East (Fisher 1976).

This shallow marine to fluvial sedimentation continued for a period of about 200 My from the Ordovician into the Permian, resulting in thick piles of sediments. Their source was the highlands that were rising to the east during the Taconic orogeny (Ordovician) and the Acadian orogeny (Devonian).

Acadian Orogeny

The Acadian orogeny (~360 Ma) continued the mountain building of the Taconic orogeny as the African continent approached North America (Harris et al. 1997). Similar to the preceding Taconic orogeny, the Acadian event involved land mass collision, mountain building, and regional metamorphism (Means 1995). This event focused farther north than central Maryland.

Alleghenian Orogeny

Following the Acadian orogenic event, the proto-Atlantic Iapetus Ocean was completely destroyed during the Late Paleozoic as the North American and African continents collided. This collision formed the Pangaea supercontinent and the Appalachian mountain belt we see today. This mountain building episode, termed the Alleghanian orogeny (~325–265 Ma), is the last major orogeny of the Appalachian evolution (fig. 14A) (Means 1995).

The rocks deformed by folding and faulting to produce the Sugarloaf Mountain anticlinorium and the Frederick Valley synclinorium in the western Piedmont, the Blue Ridge–South Mountain anticlinorium, and the numerous folds of the Valley and Ridge province (Southworth et al. 2001). During this orogeny, rocks of the Great Valley, Blue Ridge, and Piedmont provinces were transported as a massive block (Blue Ridge– Piedmont thrust sheet) westward onto younger rocks of the Valley and Ridge along the North Mountain fault. The amount of compression was extreme. Estimates were of 20–50 % shortening which translates into 125–350 km (75–125 miles) of movement (Harris et al. 1997).

Deformed rocks in the eastern Piedmont were also folded and faulted, and existing thrust faults were reactivated as both strike slip and thrust faults during the Alleghanian orogenic events (Southworth et al. 2001). Paleoelevations of the Alleghenian Mountains are estimated at approximately 6,000 m (20,000 ft), analogous to the modern day Himalaya Range in Asia. These mountains have been beveled by erosion to elevations less than 1,234 m (4,051 ft) west of National Capital Parks–East in Shenandoah National Park (Means 1995).

Triassic Extension to Cenozoic Deposition

A period of rifting began during the late Triassic and following the Alleghenian orogeny as the deformed rocks of the joined continents began to break apart about 230–200 Ma (fig. 14B). The supercontinent Pangaea was segmented into roughly the continents that persist today. This episode of rifting or crustal fracturing initiated the formation of the current Atlantic Ocean and caused many block- fault basins to develop within the continent. Pervasive volcanism accompanied these rifts (Harris et al. 1997; Southworth et al. 2001; Diecchio and Gottfried 2004).

The Newark Basin system is a large component of this tectonic event. Large alluvial fans and streams carried debris shed from the uplifted Blue Ridge and Piedmont provinces. This debris was deposited as nonmarine shales and sandstones in fault- created troughs such as the Frederick valley in central Maryland and the Culpeper basin in the western Piedmont of central Virginia. Many of these rifted openings became lacustrine basins for thick deposits of siltstones and sandstones.

Large faults formed the western boundaries of the basins and provided escarpments that were quickly covered with eroded debris. Igneous rocks intruded into the new sandstone and shale strata as sub- horizontal sheets, or sills, and near- vertical dikes that extend beyond the basins into adjacent rocks. After these molten igneous rocks were emplaced approximately 200 Ma, the region underwent a period of slow uplift and erosion. The uplift was in response to isostatic adjustments within the crust, which forced the continental crust upwards and exposed it to erosion (fig. 14C). Erosion preferentially removed the less resistant sedimentary rocks, leaving the igneous intrusions present as topographic highs on the landscape (Diecchio and Gottfried 2004).

Thick deposits of unconsolidated gravel, sand, and silt were shed from the eroded Alleghenian mountains. These sediments were deposited at the base of the mountains as alluvial fans and spread eastward to be part of the Atlantic Coastal Plain (Duffy and Whittecar 1991; Whittecar and Duffy 2000; Southworth et al. 2001). The amount of erosion inferred from sediment thickness and from the now exposed metamorphic rocks is immense. Many of the rocks exposed at the surface must have been at least 20 km (~10 miles) below the surface prior to regional uplift and erosion.

Units exposed in the Chesapeake Bay area of Mesozoic (Cretaceous Potomac Formation) and Cenozoic age were deposited in a tectonic downwarp known as the Salisbury embayment. This low area stretches from southern New Jersey to southern Virginia, bounded by the New Jersey and Norfolk arches to the north and south, respectively (Ward and Powars 2004).

The arches are characterized by thinning or truncation of the sedimentary layers over crystalline basement rocks at depth. Within the Salisbury embayment, the underlying basement complex is a structural low. Various tectonic models attempt to explain these structural differences including block faulting and transverse movement of portions of the Coastal Plain as well as sediment loading and subsidence (Ward and Powars 2004). The best explanation incorporates several of these mechanisms working in concert to create the Salisbury embayment.

Lower to Middle Tertiary sediments in the embayment record periodic marine transgressions (rises in sea level). These sediments are rich in marine shelf deposits and indicate a temperate to sub- tropical climate for the area throughout the Tertiary (Ward and Powards 2004). Significant pulses of marine transgression during the Tertiary are the result of both tectonic shifts beneath the embayment and global climate changes. Major transgressions occurred during the Paleocene, the Eocene (the greatest during the Middle Eocene resulting in the Piney Point Formation deposition), the Late Oligocene, and the Middle and Late Miocene (Ward and Powars 2004).

Quaternary Landscape Evolution

Since the breakup of Pangaea and the uplift of the Appalachian Mountains, the North American plate has continued to drift toward the west. The isostatic adjustments that uplifted the continent after the Alleghenian orogeny continued at a subdued rate throughout the Cenozoic Period (Harris et al. 1997). This adjustment influences the erosion that continues today with the Potomac, Rappahannock, Rapidan, Monocacy, and Shenandoah rivers and tributaries such as the Anacostia River stripping the Piedmont and Atlantic Coastal Plain sediments, lowering the mountains, and depositing alluvial terraces to create the present landscape (fig. 14D).

The landscape and geomorphology of the greater Potomac River valley are the result of erosion and deposition from about the mid- part of the Cenozoic Period to the present, or at least the last 5 million years. The distribution of flood plain alluvium and ancient fluvial terraces of the rivers and adjacent tributaries record the historical development of the drainage system. There is little to no evidence that the rivers and tributaries migrated laterally across a broad, relatively flat region. It seems that the rivers have cut downward through very old, resistant rocks, overprinting their early courses (Southworth et al. 2001). The rolling landscape present at National Capital Parks–East attests to this downward cutting and overprinting.

The position, distribution, thickness, and elevation of terraces and the sediments deposited on them along the rivers vary by province and rock type. The elevations of terraces along the rivers show that the slope values of the ancient and modern river valleys are similar, which suggests that the terraces formed as the result of either eustatic sea level drop or uplift (Zen 1997a, b).

There are at least six different terrace levels in the Washington, D.C., area. The oldest of these terraces is located on the crest of Glade Hill in Great Falls Park. Here the river cut though bedrock and left deposits of large quartzite and diabase boulders. In creating these terraces, the erosional features left behind as islands, islets, pinnacles, oxbows, shoestring canals, potholes, and plungepools dot the landscape along the Potomac River today (Southworth et al. 2001).

Although glaciers from the Pleistocene ice ages never reached the central Maryland area (the southern terminus was in northeastern Pennsylvania), the colder climates of the ice ages played a role in the formation of the landscape at National Capital Parks–East. The periglacial conditions that must have existed near the glaciers intensified weathering and other erosional processes (Harris et al. 1997). The landforms and deposits are probably late Tertiary to Quaternary in age when a wetter climate, sparse vegetation, and frozen ground caused increased precipitation to run into the ancestral river channels, enhancing downcutting and erosion by waterways (Means 1995; Zen 1997a, b).

Given the erodability of the unconsolidated deposits throughout the area, dating of recent tectonic and climatic regimes is problematic. Most of the sediments have eroded away. However, loess deposits (wind blown silt- sized particles, frequently associated with glaciation) found on stable landforms in surrounding areas indicate that the local transition from a colluvial- dominated (slope processes) to a fluvial- dominated (river processes) geomorphic regime did not occur in the mid-Atlantic region until the end of the early Holocene (Feldman et al. 2000). Similarly, geologists measure the oxygen isotope ratios in pedogenic clays such as kaolinite (formed from the weathering of muscovite and microcline) to determine the climatic conditions during weathering. In the Piedmont province (and by extension the Atlantic Coastal Plain), a cooler climate persisted beyond the Pleistocene glacial stage in North America (Elliott et al. 1997).

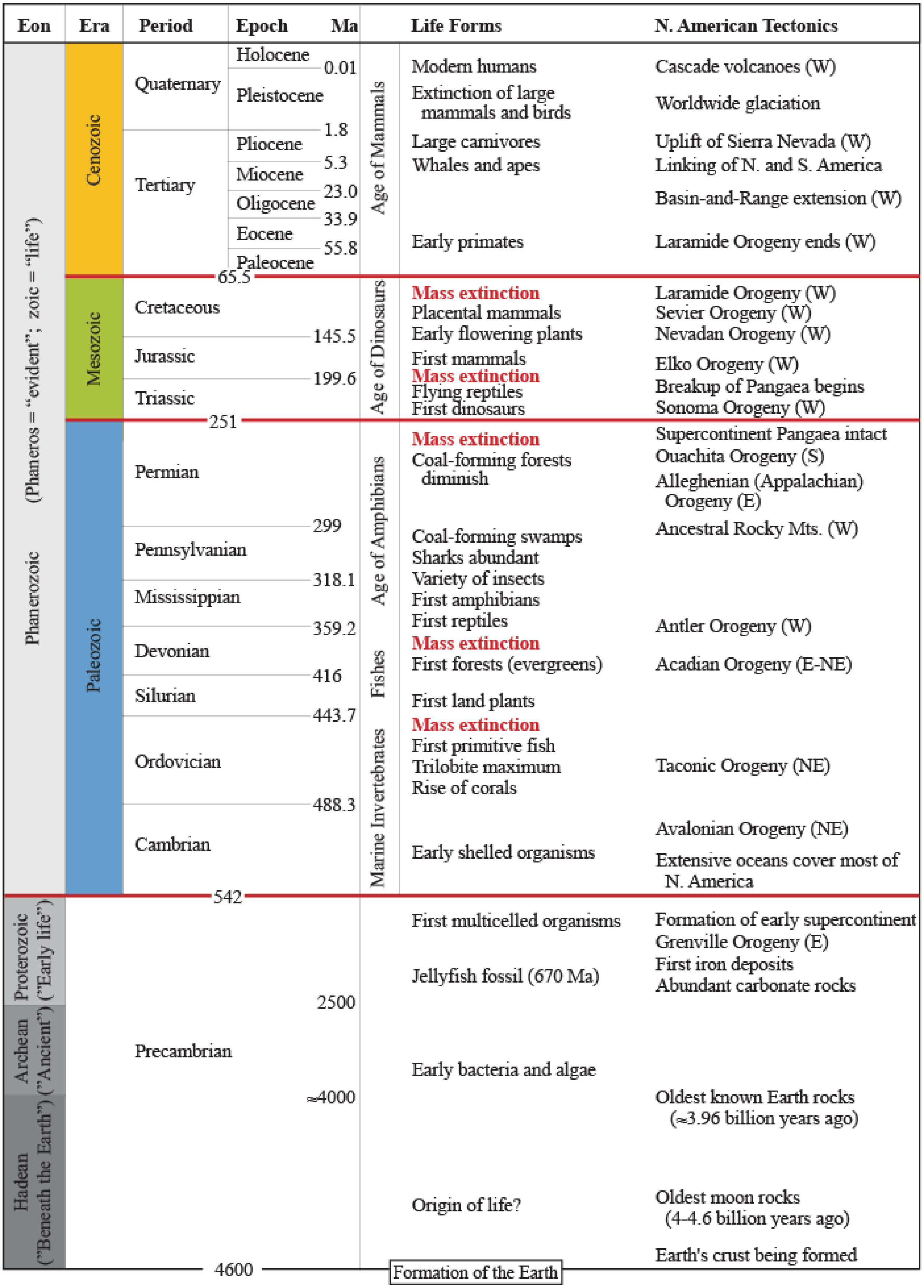

Figure 10: Geologic time scale; adapted from the U.S. Geological Survey. Red lines indicate major unconformities between eras. Included are major events in the history of life on Earth and tectonic events occurring on the North American continent. Absolute ages shown are in millions of years (Ma, or mega-annum).

Figure 11: Geologic time scale specific to Virginia-Maryland. Dates are approximate. Modified from Bailey and Roberts 1997–2003.

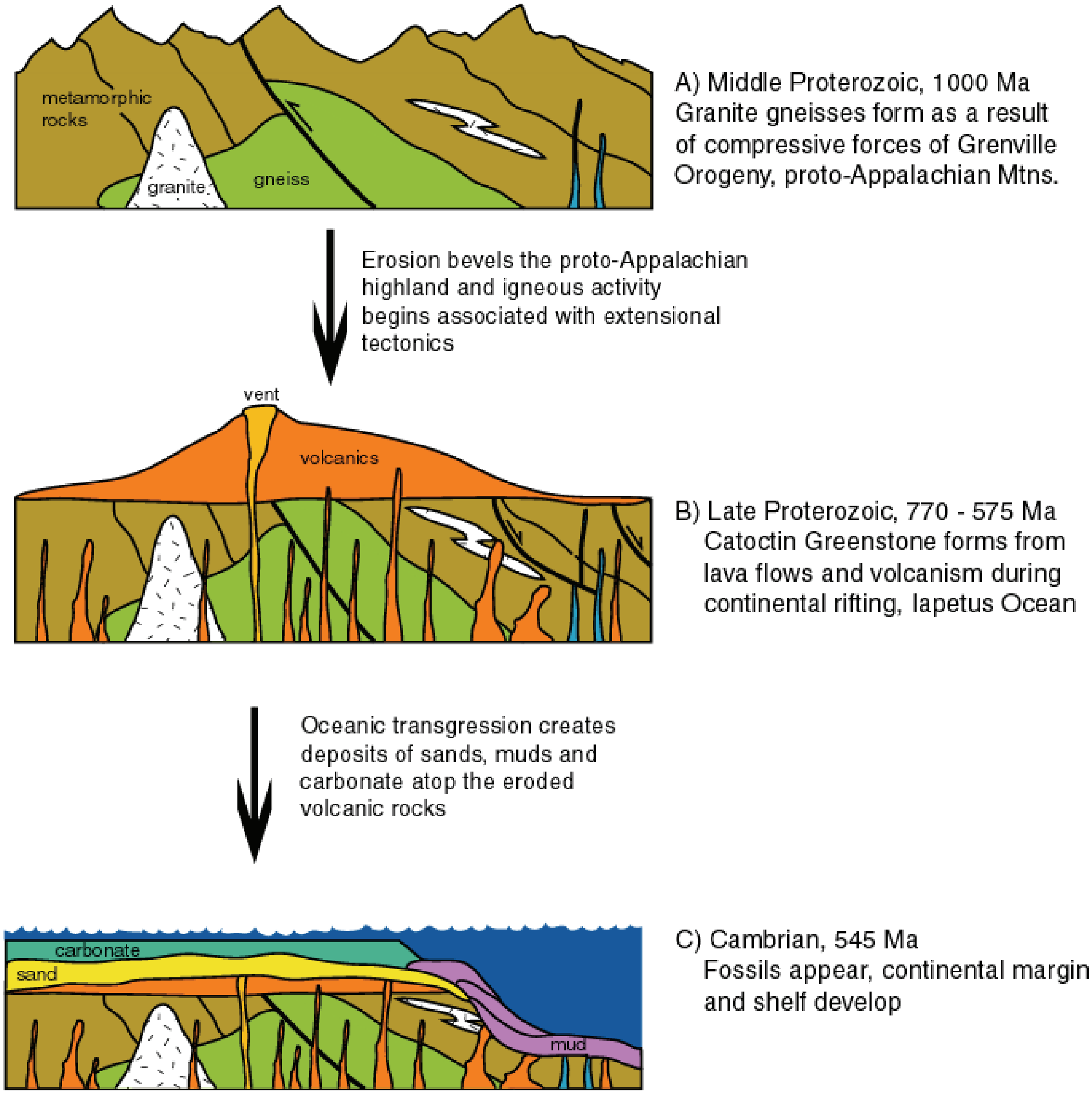

Figure 12: Geologic evolution of the Appalachian Mountains in the National Capital area. West to east cross sectional view. A) First, intrusions of granitic gneiss, metamorphism, and deformation related to the Grenville orogeny lasted 60 million years from 1.1 billion to 950 million years ago. These rocks are found in the Blue Ridge province. B) Then, continental rifting and volcanic activity in the Grenville terrane (current Blue Ridge province), and turbidites deposited in deep water basin to the east (current Piedmont province), lasted about 200 million years, from about 770 to 575 million years ago. C) Next, the margin of the continent became stable with carbonate rocks deposited in quiet water (rocks of the current Great valley and Frederick valley). Fossil shells appeared about 545 million years ago. Then, deep-water rocks were deposited into a basin east of the shelf margin for about 65 million years. Adapted from Southworth et al., (2001).

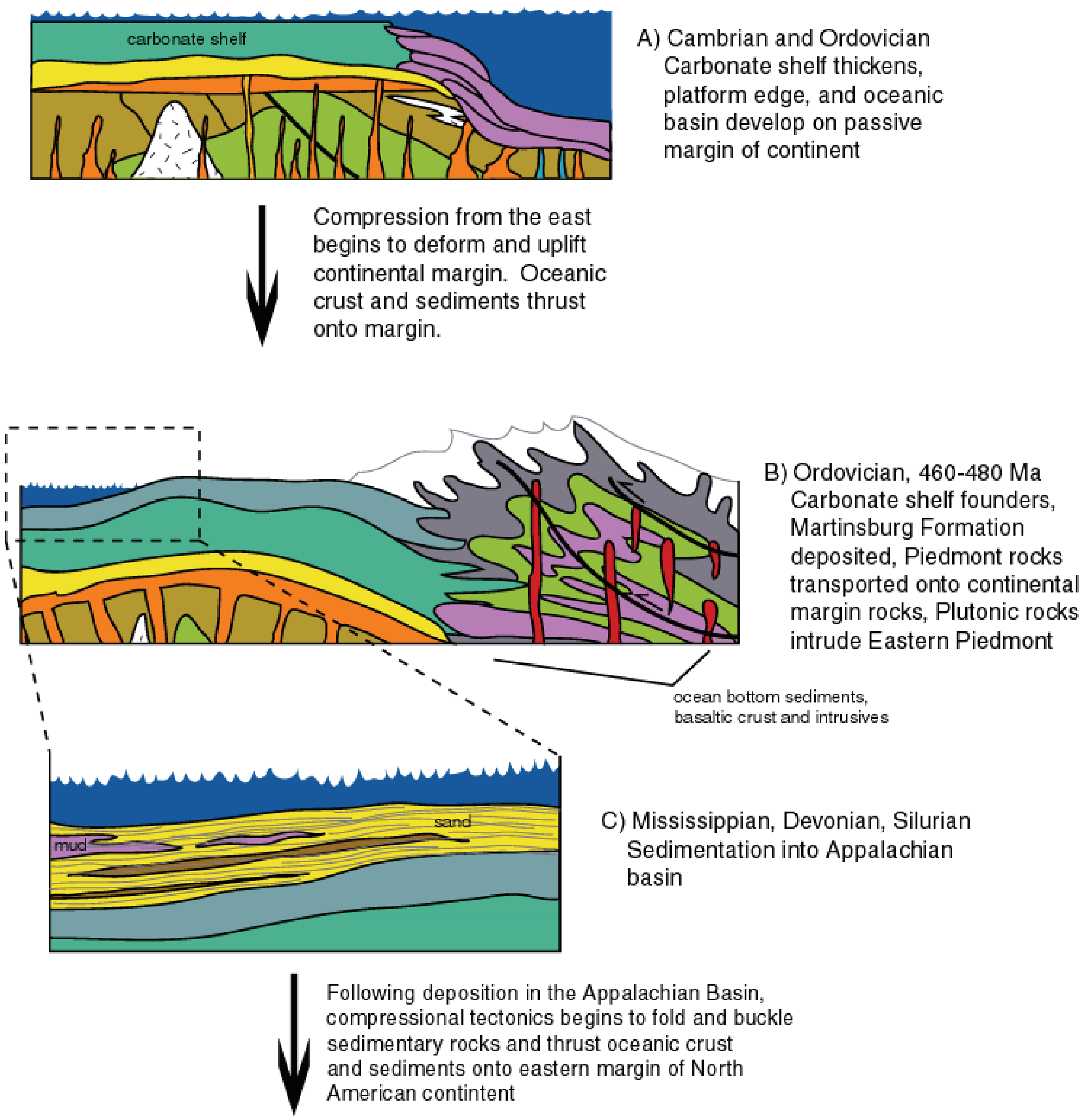

Figure 13: A) Following deposition, the stable shelf was destroyed as the Taconic orogeny, (B) (480–460 Million years ago) elevated the rocks to the east and provided a source for the clastic material that make up the shale of the Martinsburg Formation. Plutonic rocks intruded rocks in the Piedmont province. C) Then, a thick sequence of sedimentary rocks was deposited in a deepening Appalachian Basin for 120 Million years. Most of these rocks are now found in the Valley and Ridge province. Igneous rocks were intruded in rocks near Great Falls about 370 million years ago. Adapted from Southworth et al. (2001).

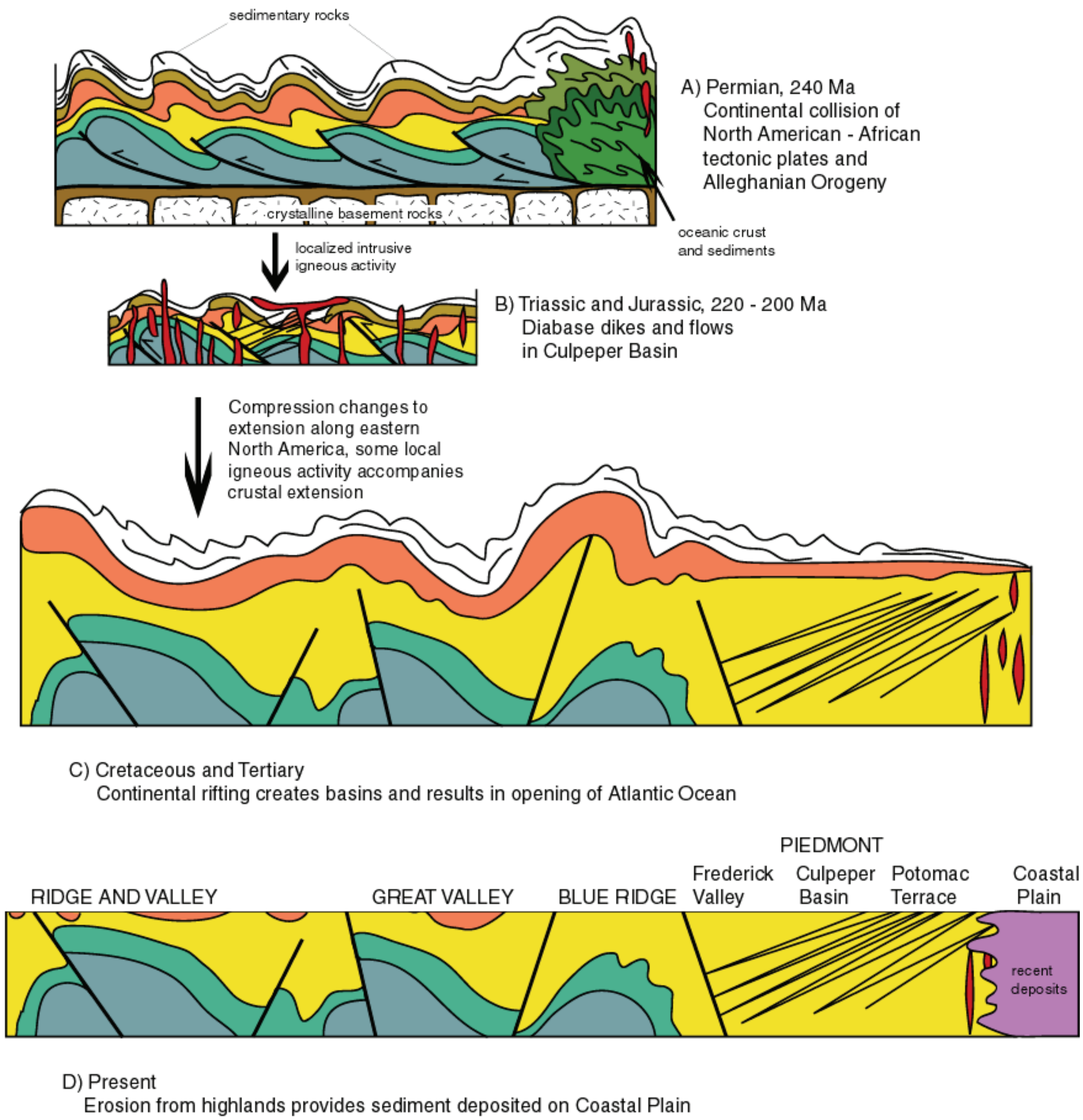

Figure 14: A) About 240 Ma, the continental tectonic plates of North America and Africa collided, resulting in the Alleghanian orogeny. Many of the folds and faults in rocks west of the Piedmont province are related to this event. B) About 20 million years later, continental rifting began and lasted for about 20 million years (220 to 200 Ma). C) Thick sequences of sedimentary rock were deposited in fault-bounded basins, there was volcanic activity, and the result was the opening of the Atlantic Ocean. The Culpeper and Gettysburg basins in the western Piedmont are the result of this event. D) For the last 200 million years, the landscape has eroded and rivers have carried the sediment eastward to deposit the thick strata of the Atlantic Coastal Plain. Diagrams are not to scale and are broadly representative of the tectonic settings. Adapted from Southworth et al. (2001).

Glossary

This glossary contains brief definitions of technical geologic terms used in this report. Not all geologic terms used are referenced. For more detailed definitions or to find terms not listed here please visit: http://wrgis.wr.usgs.gov/docs/parks/misc/glossarya.html.

alluvial fan. A fan- shaped deposit of sediment that accumulates where a high- gradient stream flows out of a mountain front into an area of lesser gradient such as a valley.

alluvium. Stream- deposited sediment that is generally rounded, sorted, and stratified.

anticlinorium. A regional anticlinal (convex up) structure composed of lesser folds.

aquifer. Body of rock or sediment that is sufficiently porous, permeable, and saturated to be useful as a source of water.

arenite. A sedimentary rock composed of sand- sized particles, regardless of composition, e.g. sandstone.

ash (volcanic). Fine pyroclastic material ejected from a volcano (also see **tuff**).

barrier island. A long, low, narrow island formed by a ridge of sand that parallels the coast.

base flow. Streamflow supported by groundwater flow from adjacent rock, sediment, or soil.

basement. The undifferentiated rocks, commonly igneous and metamorphic, that underlie identified rock units.

basin (structural). A doubly plunging syncline in which rocks dip inward from all sides (also see **dome**).

basin (sedimentary). Any depression, from continental to local scale, into which sediments are deposited.

bed. The smallest sedimentary **strata** unit, commonly ranging in thickness from 1 centimeter to a meter or two and distinguishable from beds above and below.

bedding. Depositional layering or stratification of sediments.

bedrock geology. The geology of underlying solid rock as it would appear with the sediment, soil, and vegetative cover stripped away.

bioturbation. The churning, stirring, and mixing of sediment by organisms.

block (fault). A crustal unit bounded by faults, either completely or in part.

calcareous. A rock or sediment containing calcium carbonate.

chemical sediment. A sediment precipitated directly from solution (also called nonclastic).

chemical weathering. The dissolution or chemical breakdown of minerals at Earth's surface via reaction with water, air, or dissolved substances.

clastic. Rock or sediment made of fragments of preexisting rocks.

clay. Clay minerals or sedimentary fragments the size of clay minerals (grain size <0.002 mm).

continental crust. The type of crustal rocks underlying the continents and continental shelves; having a thickness of 25–60 km (16–37 mi) and a density of approximately 2.7 grams per cubic centimeter.

cross section. A graphical interpretation of geology, structure, and (or) stratigraphy in the third (vertical) dimension based on mapped and measured geological extents and attitudes depicted in an oriented vertical plane.

crust. The outermost compositional shell of Earth, 10–40 km (6–25 mi) thick, consisting predominantly of relatively low density silicate minerals (also see **oceanic crust** and **continental crust**).

crystalline. Describes the structure of a regular, orderly, repeating geometric arrangement of atoms.

deformation. A general term for the process of faulting, folding, shearing, extension, or compression of rocks as a result of various Earth forces.

delta. A sediment wedge deposited at a stream's mouth where it flows into a lake or sea.

dike. A tabular, discordant igneous intrusion.

dinocyst. A spore of dinoflagellate, abundant in the fossil record

dip. The angle between a structural surface and a horizontal reference plane measured normal to their line of intersection.

drainage basin. The total area from which a stream system (or watershed) receives or drains precipitation runoff.

estuary. The seaward end or tidal mouth of a river where fresh and sea water mix; many estuaries are drowned river valleys caused by sea- level rise (transgression) or coastal subsidence.

eustatic. Relates to simultaneous worldwide rise or fall of sea level in Earth's oceans.

fan delta. An alluvial fan that builds into a standing body of water. The landform differs from a delta in that a fan delta is next to a highland and typically forms at an active margin.

fault. A subplanar break in rock along which relative movement occurs between the two sides.

felsic. Pertaining to a fine- grained igneous rock composed of light colored- minerals, e.g. quartz, feldspar.

formation. Fundamental rock- stratigraphic unit that is mappable and lithologically distinct from adjoining **strata** and has definable upper and lower contacts.

graben. A down- dropped structural block bounded by steeply dipping normal faults (also see **horst**).

igneous. Refers to a rock or mineral that originated from molten material; one of the three main classes or rocks: igneous, metamorphic, and sedimentary.

intrusion. A body of igneous rock that invades older rock. The invading rock may be a plastic solid or magma that pushes its way into the older rock.

isostatic. The condition of equilibrium; the weight of glaciers, water, or sediment load causes isostatic depression or downwarping, and removal of the load results in isostatic uplift (rebound) or upwarping.

karst topography. Topography characterized by abundant sinkholes and caverns formed by the dissolution of calcareous rocks.

lacustrine. Pertaining to, produced by, or inhabiting a lake or lakes.

lamprophyre. A porphyritic igneous rock with phenocrysts of mafic minerals (esp. biotite, hornblende, and pyroxene) and a fine- grained groundmass of the same mafic minerals plus feldspar.

landslide. Any process or landform resulting from rapid mass movement.

lava. Magma that has been extruded out onto Earth's surface, both molten and solidified.

leucosome. The light- colored part of a migmatite composed mainly of quartz and feldspar.

levees. Raised ridges lining the banks of a stream; may be natural or artificial.

lithification. The conversion of sediment into solid rock.

lithology. The description of a rock or rock unit, especially the texture, composition, and structure of sedimentary rocks.

lithosphere. The relatively rigid outmost shell of Earth's structure, 50–100 km (31–62 mi) thick, that encompasses the crust and uppermost mantle.

loess. Silt- sized sediment deposited by wind, generally of glacial origin.

mafic. Pertaining to an igneous rock composed of dark colored- minerals containing iron and magnesium, e.g. olivine, diopside (pyroxene), hornblende (amphibole).

magma. Molten rock generated within Earth that is the parent of igneous rocks.

mantle. The zone of Earth's interior between crust and core.

mechanical weathering. The physical breakup of rocks without change in composition (syn: physical weathering).

meta-. A prefix used before the name of an igneous or sedimentary rock to indicate metamorphism, e.g. metagabbro and metapyroxenite

metamorphic. Pertaining to the process of metamorphism or to its results.

metamorphism. Literally, "change in form." Metamorphism occurs in rocks with mineral alteration, genesis, and (or) recrystallization from increased heat and pressure.

migmatite. Literally, "mixed rock" with both igneous and metamorphic characteristics due to partial melting during metamorphism.

mineral. A naturally occurring, inorganic crystalline solid with a definite chemical composition or compositional range.

monzogranite. A variety of granite having Ca- feldspar and plagioclase in equal amounts.

normal fault. A dip- slip fault in which the hanging wall moves down relative to the footwall.

oceanic crust. Earth's crust formed at spreading ridges that underlies the ocean basins. Oceanic crust is 6–7 km (3–4 mi) thick and generally of basaltic composition.

orogeny. A mountain- building event, particularly a well-recognized event in the geologic past. (The Laramide orogeny is one well- recognized example.)

outcrop. Any part of a rock mass or formation that is exposed or "crops out" at Earth's surface.

overbank deposits. Alluvium deposited outside a stream channel during flooding.

paleontology. The study of the life and chronology of Earth's geologic past based on the phylogeny of fossil organisms.

Pangaea. A theoretical, single supercontinent that existed during the Permian and Triassic.

passive margin. A tectonically quiet continental margin indicated by little volcanic or seismic activity.

pebble. Generally, small, rounded rock particles from 4 to 64 mm in diameter.

pegmatite. A very coarse- grained intrusive igneous rock, usually occurring as dikes, lenses or veins; composition is similar to granite but often with rare minerals rich in lithium, boron, fluorine, niobium, etc.

phyllite. A metamorphic rock intermediate in grade between slate (low) and mica schist; has a silky sheen from presence of chlorite, sericite, and graphite.

plateau. A broad, flat- topped topographic high of great extent and elevation above the surrounding plains, canyons, or valleys (both land and marine landforms).

plate tectonics. The theory that the lithosphere is broken up into a series of rigid plates that move over Earth's surface above a more fluid asthenosphere.(Compare **lithosphere** and **asthenosphere**.)

pluton. A body of intrusive igneous rock.

plutonic. Describes igneous rock intruded and crystallized at some depth in Earth.

porosity. The proportion of void space (cracks, interstices) in a volume of a rock or sediment.

pyroxenite. An ultramafic intrusive igneous rock composed mainly of pyroxene (e.g., diopside, augite, hypersthene) with hornblende, biotite, or olivine.

recharge. Infiltration processes that replenish ground water.

regression. A long- term seaward retreat of the shoreline or relative fall of sea level.

sandstone. Clastic sedimentary rock of predominantly sand sized grains.

scarp. A steep cliff or topographic step resulting from vertical displacement on a fault or by mass movement.

seafloor spreading. The process in which tectonic plates diverge and new lithosphere is created at oceanic ridges.

sediment. An eroded and deposited, unconsolidated accumulation of lithic and mineral fragments.

sedimentary rock. A consolidated and lithified rock consisting of detrital and (or) **chemical sediment**(s).

shale. A clastic sedimentary rock made of clay- sized particles that exhibit parallel splitting properties.

sill. A tabular, igneous intrusion that is concordant with the country rock.

silt. Clastic sedimentary material intermediate in size between very fine sand and coarse clay (1/256- 1/16 mm).

siltstone. A variably lithified sedimentary rock with silt-sized grains.

slope. The inclined surface of any geomorphic feature or rational measurement thereof (syn: gradient).

slump. A generally large, coherent mass movement with a concave- up failure surface and subsequent backward rotation relative to the slope.

soil. Surface accumulation of weathered rock and organic matter capable of supporting plant growth and often overlying the parent rock from which it formed.

spring. A site where water flows out at the surface due to the water table intersecting the ground surface.

strata. Tabular or sheetlike masses or distinct layers (as, of rock).

stratigraphy. The geologic study of the origin, occurrence, distribution, classification, correlation, and age of rock layers, especially sedimentary rocks.

strike. The compass direction of the line of intersection that an inclined surface makes with a horizontal plane.

strike-slip fault. A fault with measurable offset where the relative movement is parallel to the strike of the fault.

subduction zone. A convergent plate boundary where oceanic crust descends beneath a continental or oceanic plate and is carried down into the mantle.

subsidence. The gradual sinking or depression of part of Earth's surface.

synclinorium. A regional synclinal (concave) structure composed of lesser folds.

taeniodont. A member of an extinct order (Taeniodonta) of mammals that lived in North America throughout the Paleocene and into the middle Eocene Epoch. Taeniodonts may have been related to early insect-eating mammals; varied in size from a rat to a bear

tectonic. Relating to large- scale movement and deformation of Earth's crust.

terraces (stream). Step- like benches surrounding the present flood plain of a stream due to dissection of previous flood plain(s), stream bed(s), and (or) valley floor(s).

terrane. A region or group of rocks similar in age, often fault- bounded with complex metamorphic, igneous, and/or structural geology.

terrestrial. Relating to Earth or Earth's dry land.

thrust fault. A contractional, dip- slip fault with a shallowly dipping fault surface (<45°) where the hanging wall moves up and over relative to the footwall.

topography. The general morphology of Earth's surface including relief and location of natural and anthropogenic features.

transgression. Landward migration of the sea due to a relative rise in sea level.

trend. The direction or azimuth of elongation of a linear geologic feature.

trondhjemite. A light- colored intrusive igneous rock composed mainly of Na- plagioclase (oligoclase), quartz, with sparse biotite and little or no Ca- feldspar; plagiogranite, leucocratic tonalite.

tuff. Generally fine grained igneous rock formed of consolidated volcanic ash.

uplift. A structurally high area in Earth's crust, produced by movement that raises the rocks.

volcanic. Related to volcanoes; describes igneous rock, such as **lava**, crystallized at or near Earth's surface.

water table. The upper surface of the saturated (phreatic) zone.

weathering. The set of physical, chemical, and biological processes by which rock is broken down in place.

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Appendix A: Geologic Map Graphic

The following page is a preview or snapshot of the geologic map for National Capital Parks–East. For a poster size PDF of this map or for digital geologic map data, please see the included CD or visit the GRE publications webpage: http://www2.nature.nps.gov/geology/inventory/gre_publications.cfm

Appendix B: Scoping Summary

The following excerpts are from the GRE scoping summary for National Capital Parks–East. The scoping meeting was held on April 30–May 2, 2001; therefore, the contact information and Web addresses referred to in this appendix may be outdated. Please contact the Geologic Resources Division for current information.

Summary and Overview

Geologic Resource Evaluation (GRE) workshops were held for National Park Service (NPS) Units in the National Capital Region (NCR) April 30–May 2, 2001. The purpose was to view and discuss the park's geologic resources, to address the status of geologic mapping for compiling both paper and digital maps, and to assess resource management issues and needs. Cooperators from the NPS Geologic Resources Division (GRD), Natural Resources Information Division (NRID), individual NPS units in the region, and the United States Geological Survey (USGS) were present for the workshop.

This workshop involved half- day field trips to view the geology of Catoctin Mountain Park, Harpers Ferry NHP, Prince William Forest Park and Great Falls Park, as well as another full- day scoping session to present overviews of the NPS Inventory and Monitoring (I&M) program, the GRD, and the on- going GRE. Round table discussions involving geologic issues for all parks in the National Capital Region included the status of geologic mapping efforts, interpretation, paleontologic resources, sources of available data, and action items generated from this meeting.

It is stressed that the emphasis of the inventory is not to routinely initiate new geologic mapping projects, but to aggregate existing "baseline" information and identify where serious geologic data needs and issues exist in the National Park System. In cases where map coverage is nearly complete (ex., having only 4 of 5 quadrangles for Park "X") or maps simply do not exist, then funding may be available for geologic mapping.

After introductions by the participants, Tim Connors presented overviews of the Geologic Resources Division, the NPS I&M Program, the status of the natural resource inventories, and the GRE in particular.

Pete Chirico (USGS–Reston, VA) demonstrated the digital geology of Harpers Ferry and also showed the group potential uses of a digital geologic coverage with his examples for Anacostia and Cumberland Island. The USGS also showed various digital products that they have developed already for Chesapeake and Ohio Canal NHP and Great Falls.

Geologic Mapping

Existing Geologic Maps and Publications

After bibliographies were assembled, a separate search was made for any existing surficial and bedrock geologic maps for the National Capital Region parks. The bounding coordinates for each map were noted and entered into a GIS to assemble an index geologic map. Separate coverages were developed based on scales (1:24,000, 1:100,000, etc.) available for the specific park. Numerous geologic maps at varying scales and vintages cover the area. Index maps were distributed to each workshop participant during the scoping session.

Status

The index of published geologic maps is a useful reference for the NCR. However, some of these maps are dated and are in need of refinement, and in other places there is no existing large- scale coverage available. The USGS began a project to map the Baltimore–Washington, D.C., area at 1:100,000 scale and as a result it was brought to their attention that modern, large- scale geologic mapping for the NCR–NPS areas would be beneficial to NPS resource management.

Because of this, the USGS developed a proposal to re-map the NCR at large scale (1:24,000 or greater) and to supply digital geologic databases to accompany this mapping. Scott Southworth (USGS–Reston, VA) is the project leader and main contact.

The original PMIS (Project Management Information Systems) statement is available in Appendix C and on the NPS intranet (PMIS number 60900); of note is that portions of it need to be changed to reflect that the source of funding will be Inventory and Monitoring funds and *not* NRPP.

Desired Enhancements in the Geologic Maps for NCR Parks

To better facilitate the geologic mapping, Scott Southworth would like to obtain better topographic coverage for each of the NCR units. Tammy Stidham knows that some of these coverages are already available and will supply them to Scott and the USGS. In general, anything in Washington, D.C., proper has 1 meter topographic coverage and Prince George's county has 1:24,000 coverage.

Notes on National Capital Parks–East (NACE)

Prioritize the parks 1–12:

- Ft. Washington (gypsum crystals, Paleontology, seeps)
- Piscataway (significant paleontology, seeps); located in Prince George's and Charles counties
- Greenbelt Park
- Oxon Run Parkway in D.C.
- Fort Circle Parks in D.C. with the exception of Forts Foote, Stanton, and Mayhan
- Oxon Cove Park
- Anacostia and Kenilworth parks; separate but contiguous
- Baltimore- Washington Parkway
- Suitland Parkway
- Shepherd Parkway
- Harmony Hall
- Frederick Douglass NHS

Digital Geologic Map Coverage

The USGS will supply digital geology in ArcInfo format for all of the NCR parks. GRE staff will take these data, add the Windows help file and NPS theme manager capability to the digital geology and will supply to the region to distribute to each park in NCR.

Other Desired Data Sets for NCR

Soils

In, 2001, Pete Biggam (GRD Soil Scientist) supplied the following information in reference to soils for parks:

National Capital Parks–East is covered by portions of three soil survey areas; "District of Columbia" (MD099), "Charles County, Maryland" (MD017), and "Prince George's County, Maryland" (MD033). Both Charles County and Prince George's County are currently being updated, with Charles County scheduled to be available sometime in calendar year 2002, and Prince George's County sometime within calendar year 2003.

Paleontology

Greg McDonald (GRD Paleontologist) would like to see an encompassing, systematic Paleontological inventory for the NCR describing the known resources in all parks with suggestions on how to best manage these resources. In addition to the parks containing paleo resources in NACE, according to his current database, the following are considered "paleo parks" in the NCR:

- Chesapeake & Ohio Canal NHP
- George Washington Memorial Parkway
- Manassas NBP
- Prince William Forest Park
- Harpers Ferry NHP

Geologic Report

A "stand- alone" encompassing report on each park's geology is a major focus of the GRE. As part of the USGS proposal to map the NCR, they will be summarizing the major geologic features of each park in a report to accompany their database.

It was suggested that after the individual reports are finished that a regional physiographic report will be completed for the entire NCR.

List of Attendees for NPS National Capital Region GRE Scoping Meeting

NAME	AFFILIATION	PHONE	E- MAIL
Joe Gregson	NPS, I & M Program	970- 225- 3559	Joe_Gregson@nps.gov
Tim Connors	NPS, GRD	303- 969- 2093	Tim_Connors@nps.gov
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Lindsay McClelland	NPS, GRD	202- 513- 7185	Lindsay_mcclelland@nps.gov
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Pete Chirico	USGS	703- 648- 6950	Pchirico@usgs.gov
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Ellen Gray	NPS, NCR	202- 342- 1443, ext. 223	Ellen_gray@nps.gov
Dale Nisbet	NPS, HAFE	304- 535- 6770	Dale_nisbet@nps.gov
Suzy Alberts	NPS, CHOH	301- 714- 2211	Susan_alberts@nps.gov
Dianne Ingram	NPS, CHOH	301- 714- 2225	Dianne_ingram@nps.gov
Bill Spinrad	NPS, CHOH	301- 714- 2221	William_spinrad@nps.gov
Debbie Cohen	NPS, ANTI	301- 432- 2243	Debbie_cohen@nps.gov
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Melissa Kangas	NPS, GWMP	703- 289- 2542	Melissa_Kangas@nps.gov
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Barry Wood	NPS, GWMP	703- 289- 2543	Barry_wood@nps.gov
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Duane Donnelly-Morrison	NPS, PRWI	703- 221- 6921	Duane_donnelly-morrison@nps.gov
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Chris Jones	NPS–WOTR	703- 255- 1822	Christopher_Jones@nps.gov
Doug Curtis	NPS–NCR–NRS	202- 342- 1443, ext. 228	Doug_Curtis@nps.gov
Brent Steury	NPS–NACE	202- 690- 5167	Brent_Steury@nps.gov
Dave Russ	USGS	703- 648- 6660	Druss@usgs.gov
Tammy Stidham	NPS–RTSC	202- 619- 7474	Tammy_stidham@nps.gov
Dan Sealy	NPS–GWMP	703- 289- 2531	Dan_Sealy@nps.gov
Sue Salmons	NPS–ROCR	202- 426- 6834, ext. 33	Sue_salmons@nps.gov

Appendix C: Report of the NPS Monitoring Workshop –

Planning for the Future in the National Capital Network

The following excerpts are from the National Capital Network monitoring workshop held on July 9–11, 2002 in Shepherdstown, West Virginia. Pages 29–43 are included in this appendix as they have direct relevancy to the geologic resource evaluation of National Capital Parks–East.

B. Geology Workgroup

Purpose:

Continue the development of vital signs indicators for geologic resources in the National Capital Region of the National Park Service to provide essential information needed to preserve and enhance the region's most important geologic resources.

Outcomes:

1. Complete the geology table from previous meetings, allowing time to clarify items already in the table and identify additional information gaps
2. Prioritize items in the geology table for future monitoring efforts
3. Develop monitoring objectives for high priority threats in the geology table.
4. Develop a list of potential protocols that would meet the above monitoring objectives from the geology table.

Overview

This breakout session began by reviewing the conceptual model describing the geologic resources developed by the geology workgroup of the SAC including (1) resource components, (2) stressors to those resources, (3) sources of stressors, (4) ecological effects, and (5) potential vital signs monitoring indicators. Terminology was clarified, existing information was edited, and new information was added. The results of this discussion are captured in Table 4 below.

One point that was not captured in Table 4 (but which should be noted) is that the geology workgroup examined soil from an agricultural perspective, rather than from an engineering perspective. In addition, several people in the group commented that geology is an integrative, long- term perspective for monitoring, although there are both short- and long- term indicators that may be used to examine threats to the geological resources in the NCN.

Other topics of discussion during the morning session were urban soils and "engineered or created landscapes". Urban soils are generally horticultural in context, some of which may be "engineered" but, by far, most urban soils are not. Urban soils tend to be non- agricultural or non- forest situations where man has, to one degree or another, manipulated the landscape such that the natural soil regime no longer exists. In most cases, soil structure has been lost or redeveloped. In many cases, urban soils were composed from subsurface soils and, therefore, nothing resembling an "A" horizon exists.

Urban soils are often compacted, resulting in high bulk densities, and, as a result, have reduced oxygen content (e.g. trails, campsites, etc.). In addition, these soils are poorly drained, low in organic matter, retain little moisture, may be disconnected from the water table or capillary water, could be contaminated or have considerable "artifacts" (ash, glass, etc.), and are often depauperate in microfauna (bacteria, fungi) and macrofauna such as worms (even if most worms are non- native). Thus, many of the highly important landscape areas of National Capital Region, including the National Mall, battlefield cemeteries, visitor centers, picnic areas, trails, tow paths, etc., are places where manipulated soils need to be understood from their creation, through use and then management.

In addition, created landscapes were identified as one of the more unique, geological components of the National Capital Network (and especially, Washington DC), and for which the group felt that very little information currently was available. On one hand, these changed environments could lead to increased diversity — due to the potentially more- complex mosaic of soils and resulting vegetation communities. On the other hand, these landscapes are commonly affected by human manipulation, horticultural and agricultural practices, and urban landscaping efforts, all of which tend to lower biodiversity and lead to an increased occurrence of exotic species.

Several potential research topics were discussed: historical records of floods, sedimentation, and land use in the region. Historical records of floods should be relatively easy to find for the National Capital Region. For example, Metro records and historical documents may provide an indication of historic structures affected by flooding on a sequential basis. In addition, Jim Patterson (NPS–retired) may have a lot of background information on NCR parks.

Sediment coring may also be used to provide a historical perspective on sediment "cycling" throughout the history of this region. The use of aerial photos, as available, may provide the necessary data to examine land use change over time, changes in stream morphology over time, and shoreline change over time.

Finally, through the use of newer technologies such as LIDAR and GPS, it is possible to examine changes in topography and geomorphology, at a fine scale, which is especially important in the Piedmont and Coastal Plain areas of the National Capital Region that have little or no topographic relief (e.g. Dyke Marsh).

In the afternoon session, the workgroup focused upon ways to condense the list of 30 threats to geological resources into a more manageable size (Table 5). This proved to be a difficult task due to the varied nature of some of the components in Table 4. The first two categories, (1) nutrients and contaminants and (2) erosion and sedimentation, were natural groupings of many of the entries in Table 4. The remaining components of Table 4 were more difficult to categorize because they did not fit nicely into a single group heading. However, the workgroup was finally able to group the components into the following subject headings: nutrient and contaminant cycling, sediment cycling, engineered lands and urban soils, shoreline change, geo- hazards, human influences within the park boundary, and human influences outside the park boundary. The group next began to prioritize these subject areas, but decided that some of these categories were too contrived, or overlapped too much, to be separated out in this way.

The final geology working group session was held on Thursday morning. The group decided to continue through the prioritization process by beginning with the categories that they were satisfied with nutrient and contaminant cycling, and sediment cycling. For these two groupings, the group suggested established protocols for monitoring, wrote monitoring goals and objectives and identified potential collaborators. Once this analysis was completed for nutrient/contaminant and sediment cycling, the discussion continued for engineered lands and urban soils, shoreline change and geo- hazards.

The categories of human influences within the park boundary and human influences outside the park boundary were decided to be too broad and thus were eliminated from Table 4.
Categories were then ranked by considering the significance of the threat to the parks in the NCN, which included the following factors: amount of area affected by the threat, intensity of the threat to the resource, urgency of the threat to the resource, monitoring feasibility, and cost of monitoring.

By the end of the morning session, the group had decided upon the following categories, in priority order: nutrient and contaminant cycling, sedimentation and erosion, lack of understanding of engineered lands, shoreline change and geo- hazards. The workgroup then went back through Table 4 to assign all 30 elements to one (or more) of these specific groupings.

In addition to the work above, the workgroup noted information needs and studies of interest throughout the discussion. They are summarized below.

Information Needs:

A more recent and complete soils map for the region is needed.

Inventory information regarding land changes and the creation of lands for baseline data as well as how these lands change towards equilibrium is needed.

Are locations of air quality monitoring stations that also capture atmospheric deposition known? They need to be checked at the National Atmospheric Deposition Program (http://nadp.sws.uiuc.edu) or discussed with the air workgroup.

What about non- point source pollution monitoring in the region?

Is anyone considering the effects of acid rain on monuments in the region? There was, at one time, a long- term monitoring project regarding this process (in DC)?

Has anyone examined the flood and floodplain history of this area?

Previous studies of interest in NCR:

There were studies at 4- Mile Run beginning in the 1950's (pre- urbanization) to look at or capture the effects of urbanization.

Jeff Houser (Oak Ridge) has looked at the effects of sedimentation on streams and stream biota.

Personnel Involved:

Facilitator: Christina Wright, NPS–NCN I & M Program: and Dale Nisbet, NPS–HAFE
Participants: Joe Calzarette, Michelle Clements, Sid Covington, Dick Hammerschlag, Bob Higgins, Wright Horton, Lindsay McClelland, Wayne Newell, Scott Southworth, L. K. Thomas, and Ed Wenschhof.

Table 4. Revised conceptual model for geological resources in the NCN.

Resource Component	Stressor	Sources	Ecological Effects	Priority of Threat to Resource	Grouping used in priority table	Indicator/ Vital Sign	Protocol	Monitoring Goal	Potential contacts or collaborators
Soil	Pesticide loading	Agricultural, residential, and commercial use	Accumulation of pesticides that adhere to soil particles, causing changes to or the elimination of non- target soil fauna populations	High	1	Test soils and sediment for suite of pesticides commonly used in local area	Lithogeochemical studies (USGS), mass balance or input/output approach	Use an input/output approach to understand nutrient and contaminant cycling in the ecosystem.	Owen Bricker, Nancy Simon, Wayne Newell, Wright Horton, David Russ (USGS–Reston), Mark Nellis (USGS–Denver), USDA, EPA, USGS–NAWQA
Soil/Bedrock	Nutrient loading	Agricultural, residential and commercial use	Acidification of the soil, reduction of soil organic matter, change in soil fertility status	High	1	Soil pH, soil N and P status, soil organic matter levels	Lithogeochemical studies (USGS), mass balance or input/output approach	Use an input/output approach to understand nutrient and contaminant cycling in the ecosystem.	Owen Bricker, Nancy Simon, Wayne Newell, Wright Horton, David Russ (USGS–Reston), Mark Nellis (USGS–Denver), USDA, EPA, USGS–NAWQA
Soil/Bedrock	Change in pH, loss of buffering capacity	Acid rain, atmospheric deposition	Change in vegetation types, mycorrhiza and other soil flora, fauna	Unknown	1	Soil pH, acid neutralizing capacity (ANC)	Lithogeochemical studies (USGS), mass balance or input/output approach. Mass flow/hydrologic modeling.	Use an input/output approach to understand nutrient and contaminant cycling in the ecosystem.	Owen Bricker, Nancy Simon, Wayne Newell, Wright Horton, David Russ (USGS–Reston), Mark Nellis (USGS–Denver), USDA, EPA, USGS–NAWQA
Soil	Temperature change	Climate change	Changes in soil micro- climate	Unknown, locally high		Soil temperature/ moisture regime, changes in soil flora, fauna and mycorrhiza suite	Soil temperature and moisture monitoring. Soil organism analysis.		
Soil/Surficial Factors	Clearing of land	Soil surface exposure, development, agriculture, zoning laws (local and county governments)	Loss of soil surface cover, increased soil surface and groundwater temperatures	High	2 and 3	Soil and groundwater temperature/ moisture regime. Change in vegetation community. Land use change.	Measurement of soil surface and groundwater temperature, monitoring of bare soils in region. Land use change analysis, vegetation community analysis.	Use survey and analysis methods to evaluate changes in topography, sediment loading and water flow rates.	Rebecca Beavers (NPS–GRD), Wayne Newell, Nancy Simon, Pete Chirico (USGS–Reston), EPA–Office of Water and ORD, USGS–NAWQA, Loren Setlaw (?), Doug Curtis (NPS–CUE), Don Weeks (NPS–Denver)

Resource Component	Stressor	Sources	Ecological Effects	Priority of Threat to Resource	Grouping used in priority table	Indicator/ Vital Sign	Protocol	Monitoring Goal	Potential contacts or collaborators
Soil	Erosion	Development, land clearing, increasing impervious surface	Increased siltation, reduced productivity/ health/abundance of soil, plants, and aquatic organisms	High	2 and 4	Sediment loading, increased sedimentation and changes in sedimentation patterns, land use change, change in topography, shoreline change, change in wetland extent and condition.	Shoreline change/Wetland extent - aerial photo analysis. Change in topography - LIDAR, GPS. Changes in sedimentation - bedload analysis, storm water event sampling, total suspended solids, light penetration in water column. Condition of wetland - changes in wetland plant species, multiband aerial photography.	Use survey and analysis methods to evaluate changes in topography, sediment loading and water flow rates.	Rebecca Beavers (NPS–GRD), Wayne Newell, Nancy Simon, Pete Chirico (USGS–Reston), EPA–Office of Water and ORD, USGS–NAWQA, Loren Setlaw (?), Doug Curtis (NPS–CUE), Don Weeks (NPS–Denver)
Soil/Surficial Factors	Erosion	Development	Change in “normal” sedimentation sequence and composition	Unknown, low	2 and 4	Increased deposition, change in scouring and deposition patterns, change in hydrologic flow regimes.	See above protocols. Also, analysis of sediment cores, including an analysis of historical sediment records.	Use survey and analysis methods to evaluate changes in topography, sediment loading and water flow rates.	Rebecca Beavers (NPS–GRD), Wayne Newell, Nancy Simon, Pete Chirico (USGS–Reston), EPA–Office of Water and ORD, USGS–NAWQA, Loren Setlaw (?), Doug Curtis (NPS–CUE), Don Weeks (NPS–Denver)
Soil	Change in vegetation/ exotics	Development, nursery use of exotics	Change in soil organic matter composition, changes in soil flora and fauna, pH, nitrification rates	Unknown		Exotic species monitoring and control measures, soil chemistry, soil organic matter levels, soil pH, soil nitrification rates			
Soil, creation of new soils	Fill dirt: complete changes in soil physical and chemical composition resulting from filling in land areas with soil from another location (esp. DC)	Landfills, abandoned mines, land engineering	Changed, destroyed, or new soil profile, change in chemical composition of soil, introduction of toxics, introduction of impervious structures into soil profile, compaction. Resultant changes to biodiversity and vegetation communities. Changes to hydrologic cycle.	High – esp. urban	1 and 3	Assessment and description of soil profile, change in subsurface temperatures, change in land surface elevation profile, movement of physical debris from land, soil compaction, change in biodiversity of flora and fauna	Assessment and description of soil profile, surface and ground water monitoring (lithogeochemical studies), bulk density, porosity or other soil compaction measures.	To understand the functioning and components of engineered landscapes (components – landfills, engineered soils, etc.)	USDA–NRCS, Dick Hammerschlag (USGS–Patauxent), Wright Horton (USGS–Reston). Also see contacts for nutrient and sediment cycling.

Resource Component	Stressor	Sources	Ecological Effects	Priority of Threat to Resource	Grouping used in priority table	Indicator/ Vital Sign	Protocol	Monitoring Goal	Potential contacts or collaborators
Soil	Compaction	Visitor Use	Changes in vegetation survival, changes in soil physical properties, creation of soil crusts (an impervious surface).	Urban, locally – high	1 and 3	Monitor soil compaction, bulk density, porosity, or other soil compaction measures. Formation of soil crusts.	Soil coring, bulk density, porosity or other soil compaction measures.	To understand the effects of visitor use upon the soil profile – includes social and official trails.	
Soil	Impervious surfaces	Paving, walls, armored banks	Scouring, cutting/changing shoreline, flooding,	High	1 and 3	Increased velocity of storm water flow, land use change	Storm water event sampling, aerial photos to examine land use change.	To understand the effects of increasing impervious surfaces in the watershed upon hydrology.	Pat Bradley–EPA, USGS–NAWQA, EPA–Office of Water
Unique soils: calcareous and serpentine soils	Lack of information for these soils and soil in general	Lack of information for these soils and soil in general	Potential for damage to unknown/ unmapped resource	Unknown	1	Soils inventory work necessary.	Complete, up-to- date, high resolution soil maps	N/A	Pete Biggam–NPS, USDA–NRCS
Groundwater	Consumption of groundwater in excess of replenishment	Human, agricultural, residential, commercial use and domestic animal use	Reduced groundwater quantity, and quality. Loss of springs and seeps, wetland loss, changed of soil saturation zones. Change in drinking water quality and quantity.	High	1 and 2	Changes in groundwater table, Changes or loss of springs and seeps, change in extent of wetlands, changes in soil moisture profile.	Survey of groundwater table and groundwater chemistry. Groundwater flow monitoring wells		
Groundwater	Introduction of toxics, acid drainage (natural and mining)	Landfills, abandoned mines, land engineering, bedrock.	Reduced groundwater quality	High	1	Change in groundwater quality, quantity, and temperature. Increased toxics in groundwater.	Groundwater monitoring wells in conjunction with lithogeochemical studies (USGS), Mass balance or input/output approach	Use an input/output approach to understand nutrient and contaminant cycling in the ecosystem.	Owen Bricker, Nancy Simon, Wayne Newell, Wright Horton, David Russ (USGS–Reston), Mark Nellis (USGS–Denver), USDA, EPA, USGS–NAWQA
Groundwater	Physical Failure	Landfills, abandoned mines, land engineering	Change in subsurface water flow patterns, change in subsurface temperatures, introduction of contaminants	High	5	Groundwater monitoring wells (flow and mapping), subsurface temperature changes	Aerial photo mapping of areas with potential physical failures. Park staff observations of potential geo- hazard sites. Expert analysis of geo- hazard sites on a periodic basis.	To use observation and assessment to provide an early warning of physical failure in order to protect the resource, visitors, and park infrastructure.	John Pallister, Bula Gori, Gerry Wieczoff–USGS

Resource Component	Stressor	Sources	Ecological Effects	Priority of Threat to Resource	Grouping used in priority table	Indicator/ Vital Sign	Protocol	Monitoring Goal	Potential contacts or collaborators
Groundwater	Water bypasses the soil profile	Old – abandoned wells (farms)	Increased groundwater contamination with nutrients, pesticides and other chemicals	Unknown	1	Change in groundwater quality, increased toxics in groundwater.	Groundwater monitoring and monitoring of abandoned wells in conjunction with lithogeochemical studies (USGS), Mass balance or input/output approach. Abandoned wells need to be found and sealed to minimize contamination.	Use an input/output approach to understand nutrient and contaminant cycling in the ecosystem.	Owen Bricker, Nancy Simon, Wayne Newell, Wright Horton, David Russ (USGS–Reston), Mark Nellis (USGS–Denver), USDA, EPA, USGS–NAWQA
Groundwater	Impervious Surfaces	Roads, buildings, infrastructure	Reduced water infiltration leading to reduced groundwater recharge, movement of water between watersheds	Medium	1 and 2	Map and monitor groundwater recharge areas, monitor groundwater table levels and chemistry, subsurface temperature monitoring.			
Exposed rock	Cutting the toe of slopes, over-steepened slopes, dipslopes	Development, roads, structures, trails, flooding, vegetation death (hemlock etc.), logging	Reduced slope stability	Low	5	Slope failure, reduced slope stability, movement of materials downslope, erosion, gully formation	Aerial photo mapping of areas with potential physical failures. Park staff observations of potential geo- hazard sites. Expert analysis of geo- hazard sites on a periodic basis. Monitoring for gulley formation or increasing erosion.	To use observation and assessment to provide an early warning of physical failure in order to protect the resource, visitors, and park infrastructure.	John Pallister, Bula Gori, Gerry Wieczoff–USGS. Also see personnel under erosion categories.
Karst	Toxics: pesticides, dumping, spills	Agriculture, septic systems, sewage, dumping, industry, spills	Rapid movement of contaminants to ground water, change in ground water chemistry and resulting in change in biology	High – locally	1	Subterranean invertebrates, ground water chemistry/ quality	Analysis of subterranean invertebrates. Lithogeochemical studies (USGS), Mass balance or input/output approach	Use an input/output approach to understand nutrient and contaminant cycling in the ecosystem.	Smithsonian Institute Invertebrate specialists. Owen Bricker, Nancy Simon, Wayne Newell, Wright Horton, David Russ (USGS–Reston), Mark Nellis (USGS–Denver), USDA, EPA, USGS–NAWQA

Resource Component	Stressor	Sources	Ecological Effects	Priority of Threat to Resource	Grouping used in priority table	Indicator/ Vital Sign	Protocol	Monitoring Goal	Potential contacts or collaborators
Karst	Nutrient loading	Agriculture, septic systems, sewage, dumping, industry, spills	Rapid movement of nutrients to ground water resulting in change to ground water quality and change in biology	High – locally	1	Subterranean invertebrates, ground water nutrient content	Analysis of subterranean invertebrates. Lithogeochemical studies (USGS), Mass balance or input/output approach	Use an input/output approach to understand nutrient and contaminant cycling in the ecosystem.	Smithsonian Institute Invertebrate specialists. Owen Bricker, Nancy Simon, Wayne Newell, Wright Horton, David Russ (USGS–Reston), Mark Nellis (USGS–Denver), USDA, EPA, USGS–NAWQA
Karst	Structural collapse, sinkholes	Inappropriate construction practices, dissolution in karst areas	Change in biology due to changes in air flow and temperature, volume and flow of water increased in areas dissolution of bedrock	High – locally	5	Change in sinkhole size, aerial photos to capture surface changes, subsurface temperature monitoring	Aerial photo mapping of areas with sinkholes. Park staff observations of potential geo- hazard sites. Expert analysis of geo- hazard sites on a periodic basis.	To use observation and assessment to provide an early warning of physical failure in order to protect the resource, visitors, and park infrastructure.	John Pallister, Bula Gori, Gerry Wieczoff–USGS
Surface water	Impervious surfaces	Infrastructure, development, residential and agricultural use, rip rap, armoring etc.	Increased storm water flow, increased erosion, changes in sedimentation, changes in stream morphology, increased exposure to nutrients/ pesticides, change in hydrologic cycle effecting floodplains, and floodplain/riparian buffer capacity, change in base flow	High	1 and 2	Stream storm water flow, flood frequency, sedimentation load, stream morphology. Photo points. Storm event sampling, Mass flow/hydrologic modeling	Lithogeochemical studies (mass balance approach). Shoreline change/Wetland extent - aerial photo analysis. Change in topography - LIDAR, GPS. Changes in sedimentation - bedload analysis, storm water event sampling, total suspended solids, light penetration in water column. Condition of wetland - changes in wetland plant species, multiband aerial photography.	Use an input/output approach to understand nutrient and contaminant cycling in the ecosystem. Use survey and analysis methods to evaluate changes in topography, sediment loading and flow rates.	Rebecca Beavers (NPS–GRD), Owen Bricker, Nancy Simon, Wayne Newell, Pete Chirico, Wright Horton, David Russ (USGS–Reston), Mark Nellis (USGS–Denver), USDA, EPA–Office of Water, USGS–NAWQA

Resource Component	Stressor	Sources	Ecological Effects	Priority of Threat to Resource	Grouping used in priority table	Indicator/ Vital Sign	Protocol	Monitoring Goal	Potential contacts or collaborators
Surface water	Pesticide loading	Agricultural, residential, and commercial use	Reduced water quality, fishery health, and aquatic invertebrate communities and populations	High	1	Test for suite of pesticides commonly used in local area.	Lithogeochemical studies (USGS), Mass balance or input/output approach	Use an input/output approach to understand nutrient and contaminant cycling in the ecosystem.	Owen Bricker, Nancy Simon, Wayne Newell, Wright Horton, David Russ (USGS–Reston), Mark Nellis (USGS–Denver), USDA, EPA, USGS–NAWQA
Surface water	Nutrient loading	Agricultural, residential and commercial use	Reduced water quality, fishery health, and aquatic invertebrate communities and populations. Algal blooms, eutrophication	High	1	Soil water and stream levels of N and P. High algal growth, low light penetration	Lithogeochemical studies (USGS), Mass balance or input/output approach	Use an input/output approach to understand nutrient and contaminant cycling in the ecosystem.	Owen Bricker, Nancy Simon, Wayne Newell, Wright Horton, David Russ (USGS–Reston), Mark Nellis (USGS–Denver), USDA, EPA, USGS–NAWQA
Coastal areas	Impervious surfaces	rip rap, armoring, coastal walls, dredging	Changes in water flow rates, unnatural erosion and deposition, changes in natural shoreline, changes in sedimentation, wetland flooding, changes in wetland extent.	High – locally	1 and 2	Sedimentation coring (deep cores – research, shallow cores – monitoring), mapping of shoreline change, use of Pope's Creek as a reference area	Using aerial photos or survey methods to map shoreline and shoreline change over time.	Use mapping or survey methods to track changes in shoreline and depositional patterns, over time.	NOAA (?)
Lakes, ponds, seeps, vernal pools	Nutrient loading	Agriculture, residential lawn care, vegetation change	Eutrophication, change in fauna (esp. herps), effect upon T&E species	Unknown	1	Size/volume, chemistry, and temperature of surface water component	Lithogeochemical studies (USGS), Mass balance or input/output approach	Use an input/output approach to understand nutrient and contaminant cycling in the ecosystem.	Owen Bricker, Nancy Simon, Wayne Newell, Wright Horton, David Russ (USGS–Reston), Mark Nellis (USGS–Denver), USDA, EPA, USGS–NAWQA
Lakes, ponds, seeps, vernal pools	Pesticide loading	Agriculture, residential, and commercial use	Addition of herbicides and pesticides to surface water, change in fauna, effect upon T&E species	Unknown	1	Pesticide, herbicide content of surface water component	Lithogeochemical studies (USGS), Mass balance or input/output approach	Use an input/output approach to understand nutrient and contaminant cycling in the ecosystem.	Owen Bricker, Nancy Simon, Wayne Newell, Wright Horton, David Russ (USGS–Reston), Mark Nellis (USGS–Denver), USDA, EPA, USGS–NAWQA

Resource Component	Stressor	Sources	Ecological Effects	Priority of Threat to Resource	Grouping used in priority table	Indicator/ Vital Sign	Protocol	Monitoring Goal	Potential contacts or collaborators
Riparian areas, Wetlands	Change in soil surface elevation and horizontal dimensions	Land engineering resulting in changes to deposition and erosion, dredging, dumping, creation of impoundments and dams	Disruption to the wetland/riparian ecosystems, change in storm water flow rates, vegetation change, wildlife change, change in stream bed characteristics	High	4	High resolution riparian/ wetland elevation monitoring, vegetation monitoring, sediment budget, changes in size of wetland area	Changes in wetland extent - aerial photo analysis. Change in topography - LIDAR, GPS. Changes in sedimentation - bedload analysis, storm water event sampling, total suspended solids, light penetration in water column. Condition of wetland - changes in wetland plant species, multiband aerial photography.	Use survey and analysis methods to evaluate changes in topography, sediment loading and water flow rates.	Rebecca Beavers (NPS–GRD), Wayne Newell, Nancy Simon, Pete Chirico (USGS–Reston), Richard Lowrance (USDA/ARS), EPA–Office of Water and ORD, USGS–NAWQA, Loren Setlaw (?), Doug Curtis (NPS–CUE), Don Weeks (NPS–Denver)

Table 5. Priority threats, vital signs, and monitoring goals and objectives for geological resources in the NCN.

Threats (in priority order)	Vital Sign	Monitoring Goal	Monitoring Objectives
Nutrient and chemical contamination	Changes in soil and ground water chemistry.	Use an input/output approach to understand nutrient and contaminant cycling in the ecosystem.	(1) Measuring nutrient inputs from sources pertinent to each park unit. (2) Measuring contaminant inputs from sources pertinent to each park unit. (3) Tie information from numbers 1 and 2 to the hydrologic cycle, flood history, flood effects, and flood impacts.
Erosion and sedimentation	Changes in topography, sediment loading and deposition, shoreline change, wetland extent and condition.	Use survey and analysis methods to evaluate changes in topography, sediment loading, and flow rates.	(1) Measure loss of soil, growth of gulleys, changes in streambanks…. (2) Track sedimentation history, effects, and impacts (including streams and ponds, hillslopes and gulleys).
Lack of understanding of urban soils and engineered lands	Compaction, runoff, chemical composition, soil profile and structure, biodiversity.	To understand the functioning and components of urban soils engineered landscapes and their effects upon resident biota. Components include: highly impacted soil (compaction in and around trails, visitor centers), landfills, engineered soil, etc.	(1) Measure changes to physical components of urban soils and engineered lands and correlate with changes in resident biota (and exotic species). (2) Measure contaminant outflow from landfills, abandoned mines, etc.
Shoreline change	Inundation of wetlands, erosion and sedimentation processes.	Use mapping or survey methods to track shoreline change and depositional patterns.	(1) Measure shoreline change using aerial photos, LIDAR and survey methodologies and correlate changes to development, when possible. (2) Use sediment coring and historical data to understand long- term flood histories.
Geo- hazard	Physical failure, rock falls, landslides, sinkhole collapse.	Use observation and assessment to provide an early warning of physical failure to protect the resource, visitors, and park infrastructure.	(1) Monitor areas of potential hazard due to unstable slopes, rockfalls, etc. (2) Monitor for changes in unstable engineered sites or areas that are geologically active (e.g. Potomac Gorge). (3) Document and monitor areas underlain by swelling clays.

Appendix D: Geoindicators Report

National Capital Parks East Geoindicators Meeting

Introduction

National Capital Parks–East (NACE) comprises more than 10,000 acres of the Atlantic Coastal Plain from Anne Arundel County, Maryland, through the eastern part of Washington, D.C., to Prince George's and Charles counties, Maryland. The Coastal Plain is composed of a wedge- shaped sequence of soft sediments, deposited intermittently during periods of higher sea level over the past 100 million years. Thicknesses of coastal plain sediments reach 10,000 feet near the Maryland coast (Reed, Sigafoos, and Fisher 1980). Significant habitats include tidal and non- tidal wetlands and upland forests. Legislative purposes for some National Capital Parks–East units include preventing pollution and ensuring flow into the Potomac and Anacostia rivers. [See the National Capital Planning Commission Act of 1924. Parks established under the Act were later given to the NPS. Steve Syphax can provide language. Other NACE parks were established under the George Washington Memorial Parkway's legislation.] [Check NRBib and with Doug Curtis for information on current monitoring in NACE.]

Tributary Streams

The NACE generally owns only a small portion of its approximately 20 streams, many of which emerge from pipes into the watershed. Major streams include Henson Creek (Suitland Parkway and Harmony Hall), Fort Dupont Creek (Fort Dupont Park), Deep and Still creeks (Greenbelt Park), Oxon Run (Oxon Cove Park) and Pope and Watts branches (Kenilworth Park). Park staff exerts considerable effort in working with surrounding jurisdictions to protect stream corridors.

Research is needed on sediments, including coring and N- alkanes.

Streams in effect integrate the surface runoff and groundwater flow of their watersheds, so provide a cumulative measure of watershed hydrologic health. NACE generally manages only the downstream portions of its streams, so has little control over water quality, quantity, or sediment load. Erosion and aggradation data for NACE streams are scarce.

The most severe threats to park streams are from impacts of existing and future development in the surrounding region. Allen and Flack (2001) cite a number of specific threats, excerpted below. Their assessment of each threat severity (severe/major/moderate/minor) is given in brackets.

- Habitat fragmentation from road crossings, primarily culverts (see below for details of culvert impacts). [severe]
- Habitat destruction from high storm water flows and construction of storm water management facilities. [severe]
- Hydrologic changes from increased runoff from impervious surfaces. [severe]
- Sedimentation from land clearing activities. [major]
- Water temperature increases from runoff from heated impervious surfaces. [moderate]
- Pollution from runoff of petroleum products from impervious surfaces, and pesticides, herbicides, and fertilizers from developed land. [minor]

Allen and Flack (2001) report that impacts from impervious surfaces begin when they cover more than 10% of the watershed, and become severe above 20%, unless there is mitigation from storm water management systems.

Development impacts include increased "flashiness," a combination of reduced base flow because impervious surfaces reduce infiltration of groundwater and higher peak flow because of higher storm water runoff from impervious surfaces. Chemical pollutants such as leakage from vehicles and litter and trash that wash in from developed sites are additional impacts from impervious surfaces. Construction activities bring flushes of sediment and other debris, with volumes dependent on types of mitigation measures required and enforced by local governments. Development may also bring long- term increases in pollutants such as pesticides, herbicides, and fertilizers; organic and inorganic chemicals; metals such as mercury, arsenic, lead, and aluminum; sewage from humans and domestic animals; pharmaceuticals; and endocrine disruptors.

Development has also resulted in significant changes in elevation and slope. To create suitable building sites, hills have historically been flattened and marshes and stream valleys filled. By developing a pre- development digital elevation model (DEM) from 1889 topographic data and comparing it to current DEM data, Chirico and Epstein (2000) have documented as much as 60 feet of elevation change associated with development in parts of Philadelphia. Data for a similar project are available for Washington, D.C. U.S. Coast and Geodetic Survey 1:4,800- scale maps from 1878 and 1888 can be digitally compared to USGS topographic map data from 1996–1999. District of Columbia sewer- line maps from 1891 and 1892 are also available to show evidence of topographic modification of stream valleys. Initial work has documented significant topographic change. The District of Columbia government has tentatively funded the project, but administrative issues unrelated to this project have delayed, and may threaten, the eventual transfer of funds.

Daylighting of streams (removal from culverts) has been proposed in Anacostia Park, with the potential for significant funding from the U.S. Army Corps of Engineers (COE). A number of flood- control levees that are routinely inspected by the COE are on NPS land along the Anacostia River, in the same area that stream daylighting is being proposed. The degree of NPS responsibility to maintain these structures is uncertain. [Charles Karpowitz may be the best contact.] Daylighting might help to establish fringe wetlands, but might also impact flood control levees.

Potential monitoring targets:

- Changes in development in park tributary watersheds—incorporate detailed data from appropriate city and county maps into a GIS database, focusing on changes in impervious surfaces, road crossings, buffering vegetation, and storm water management systems.
- Streamflow, including seasonal mean flows, lowest flow rates, and timing and magnitude of storm events—develop comparative data between tributaries affected by varying degrees of development, and contrast with reference streams with watersheds dominantly or entirely within protected land if available.
- Sedimentation rates and compositions, including contributions of litter and pollution from surrounding developed areas—establish sites for repeat stream profile measurements, and reoccupy if possible shortly after major runoff events.
- Water quality data, such as pollutants, dissolved oxygen, fecal coliform, and temperature—if pollution is significant, collect data needed to identify sources within the watershed, such as malfunctioning sewer outfalls or excessive application of landscape chemicals by landowners.
- Morphologic change in stream channels—reliable measurements generally require 3–5 cross sections over several hundred meters of channel.
- Stream deltas—as surrogates for erosion and sedimentation within an entire watershed.

Existing data, with sources if available:

- Regional coordination for water quality data — Doug Curtis.
- Impacts of water quality on plants — Nancy Rybicki, USGS.
- Chesapeake Bay studies of sediment transport — Scott Phillips, 410- 238- 4200, is project coordinator; Angelica Gutierrez heads the modeling effort.

The numerous seawalls also found along the Anacostia River are an obvious effect of human engineering, but the shoreline has also been affected by a reduction in the amount of large woody debris along the shore, thus reducing its protection from erosion in some areas. Changes in shoreline position may impact coastal marshes such as those at Piscataway Park.

The NPS manages the bottom of the Anacostia River and works with the EPA on toxics issues through the Anacostia Watershed Toxics Alliance. Some toxics sites are being monitored. The NPS Water Resources Division has drilled 4–5 cores in the Anacostia River near the Washington Navy Yard, and also has piezometer data. Sediment movement may also be studied. Work on the Anacostia River is coordinated through the Metropolitan Washington Council of Governments (COG) and the Anacostia Watershed Coordination Committee. [John Galli, COG, is a good contact.]

Henson Creek is biologically valuable and has been the focus of flood studies. Accretion occurs in areas of lower gradients. The flood management plan for Henson Creek depends on active management, as advocated by Prince George's County.

Several of the parks include reclaimed sanitary landfills, all of which were operated before modern environmental standards were established for landfills. Total area covered by former landfills is about 300 acres. NACE has been working with EPA and others to monitor outflow from the landfills, to prevent leachate from reaching the Potomac and Anacostia rivers. [USGS strengths in monitoring provide the potential for valuable cooperation – Bill Banks.] In addition to water quality, groundwater level and soil quality data are important in assessing the impact of landfills. Heat is generated by chemical reactions in landfills, but there is no obvious visual or ecosystem evidence that heating is occurring above the park landfills.

The Washington Metropolitan Area Transit Authority has numerous wells at a variety of transportation sites, including near the Anacostia Metro station.

Elevation data are needed to monitor marshes such as Accokeek and the restored marsh at Kenilworth Park. Changes in elevation at the scale of one foot appear to have significant effects on vegetation type in wetlands, including the potential for invasive species to become established. Exploration of the relationship between elevation and wetland ecology are a high priority for wetland management and for assessments of methodologies and standards for restoring marshland. Chemistry of wetland soil and water should also be monitored, and ecosystem effects of chemical constituents assessed. Evolution of hydric soils on created wetlands is a potentially important factor in their evolution. [Pete Biggam will have information on soil evolution in other artificial wetlands.] The Natural Resource Conservation Service is developing new definitions of artificial soils.

Impacts on soils, sedimentation, and erosion of human activity and engineering, including facility placement, culverts, stream and storm sewer outfalls, parking lots, etc., should be assessed. Slope stability is an issue along the Shepherd and Baltimore- Washington parkways, which occasionally have landslides, as does Fort Dupont. Unstable slopes are found in the Newcomb St. area and a large wall has been required to retain a slope along O St. SE. At Greenbelt Park, monitoring of sediment inflow (originating from unstable fill) to the Yeager Tract is needed to assess whether it has stabilized.

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National Capital Parks–East

Geologic Resource Evaluation Report

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Natural Resource Program Center

The Natural Resource Program Center (NRPC) is the core of the NPS Natural Resource Stewardship and Science Directorate. The Center Director is located in Fort Collins, with staff located principally in Lakewood and Fort Collins, Colorado and in Washington, D.C. The NRPC has five divisions: Air Resources Division, Biological Resource Management Division, Environmental Quality Division, Geologic Resources Division, and Water Resources Division. NRPC also includes three offices: The Office of Education and Outreach, the Office of Inventory, Monitoring and Evaluation, and the Office of Natural Resource Information Systems. In addition, Natural Resource Web Management and Partnership Coordination are cross- cutting disciplines under the Center Director. The multidisciplinary staff of NRPC is dedicated to resolving park resource management challenges originating in and outside units of the national park system.

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